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Environmental Technology Verification Report

LAND COMBUSTION MODEL
LANCOM SERIES II
PORTABLE EMISSION ANALYZER

Prepared by



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September 2000

Environmental Technology Verification Report

ETV Advanced Monitoring Systems Center

Land Combustion Model LANCOM Series II Portable Emission Analyzer

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Notice

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA, to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permittees, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification Organizations oversee and report verification activities based on testing and Quality Assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. At present, there are twelve environmental technology areas covered by ETV. Information about each of the environmental technology areas covered by ETV can be found on the Internet at <http://www.epa.gov/etv.htm>.

Effective verifications of monitoring technologies are needed to assess environmental quality, and to supply cost and performance data to select the most appropriate technology for that assessment. In 1997, through a competitive cooperative agreement, Battelle was awarded EPA funding and support to plan, coordinate, and conduct such verification tests, for "Advanced Monitoring Systems for Air, Water, and Soil" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/etv/07/07_main.htm.

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List of Abbreviations

AMS	Advanced Monitoring Systems
ANSI	American National Standards Institute
Btu/hr	British thermal unit per hour
ccm	cubic centimeter per minute
CEM	continuous emission monitor
CO	carbon monoxide
CO ₂	carbon dioxide
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
FID	flame ionization detector
gpm	gallons per minute
kW	kilowatt
LOD	limit of detection
lpm	liters per minute
m ³	cubic meters
NH ₃	anhydrous ammonia
NIST	National Institute of Standards and Technology
NO	nitric oxide
NO _x	nitrogen oxides
NO ₂	nitrogen dioxide
O ₂	oxygen
PE	performance evaluation
ppm	parts per million, volume
ppmC	parts per million carbon
QA	quality assurance
QC	quality control
QMP	Quality Management Plan
RPM	revolutions per minute
SAS	Statistical Analysis System
SO ₂	sulfur dioxide
UHP	ultra-high purity

Chapter 1

Background

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification Program (ETV) to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase and use of environmental technologies.

ETV works in partnership with recognized testing organizations, stakeholder groups consisting of regulators, buyers and vendor organizations, and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA's National Exposure Research Laboratory and its verification organization partner, Battelle Memorial Institute, operate the Advanced Monitoring Systems (AMS) Center under ETV. The AMS Center has recently evaluated the performance of portable nitrogen oxides monitors used to determine emissions from combustion sources. This verification statement provides a summary of the test results for the Land Combustion LANCOR Series II portable emission analyzer.

Chapter 2

Technology Description

The objective of the ETV AMS Center is to verify the performance characteristics of environmental monitoring technologies for air, water, and soil. This verification report provides results for the verification testing of the Land Combustion LANCOM Series II portable emission analyzer. The following description of the LANCOM Series II analyzer is based on information provided by the vendor.

The LANCOM Series II analyzer weighs 13.2 pounds, is slightly larger than a laptop computer, and measures up to eight flue gases (O_2 , NO, NO_2 , SO_2 , CO_2 , H_2S , hydrocarbons, and CO), with both low and high ranges for CO. Analyzer options include semi-continuous monitoring (pre-determined timed sampling intervals), printing, data logging (1,000 records), and serial communications, plus various probe lengths. All gas measurements can be stored, downloaded, or printed. The LANCOM Series II analyzer offers on-board diagnostics, accessible filters and water catchpot, and a “semi-continuous” operating mode. It provides ppm conversions (mg/m^3 , lb/mBTU, lb/hr, etc.), oxygen normalization, and total NO_x , on a wet or dry basis.

The LANCOM Series II systems components are mounted on molded PVC and sheathed in corrosion-resistant plastic. The analyzer can be operated when worn on a shoulder strap or free-standing on the ground. All controls are on the top of the instrument. The batteries are mounted at the bottom of the case, which provides enhanced stability when the instrument is on the floor. The large capacity water catchpot is mounted on the side of the instrument on a hinged assembly. The particulate and chemical filters are also mounted on the side of the instrument. All measured parameters and operator interface are displayed on a full function alphanumeric/graphic liquid crystal display. The LANCOM Series II analyzer contains two 6V batteries capable of powering the instrument for eight hours in the field.

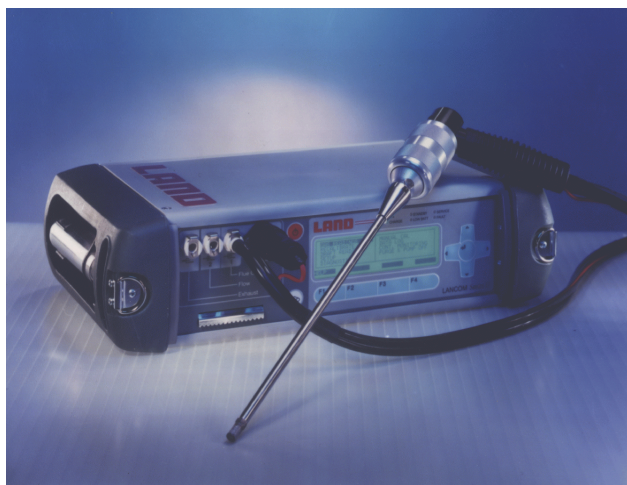


Figure 2-1. LANCOM Series II Analyzer

Chapter 3

Test Design and Procedures

3.1 Introduction

The verification test described in this report was conducted in May 2000. The test was conducted at Battelle in Columbus, Ohio, according to procedures specified in the *Test/QA Plan for Verification of Portable NO/NO₂ Emission Analyzers*.⁽¹⁾ Verification testing of the analyzers involved the following tests:

1. A series of laboratory tests in which certified NO and NO₂ standards were used to challenge the analyzers over a wide concentration range under a variety of conditions.
2. Tests using three realistic combustion sources, in which data from the analyzers undergoing testing were compared to chemiluminescent NO and NO_x measurements made following the guidelines of EPA Method 7E.⁽²⁾

The schedule of tests conducted on the LANCOM Series II analyzers is shown in Table 3-1.

To assess inter-unit variability, two identical LANCOM Series II analyzers were tested simultaneously. These two analyzers were designated as Unit A and Unit B throughout all testing. The Land representative indicated that the electrochemical sensor for NO₂ in Unit B was somewhat older than that in Unit A. The commercial analyzers were operated at all times by a representative of Land Combustion so that each analyzer's performance could be assessed without concern about the familiarity of Battelle staff with the analyzers. At all times, however, the Land Combustion representative was supervised by Battelle staff. Displayed NO and NO₂ readings from the analyzers (in ppm) were manually entered onto data sheets prepared before the test by Battelle. Battelle staff filled out corresponding data sheets, recording, for example, the challenge concentrations or reference analyzer readings, at the same time that the analyzer operator recorded data. This approach was taken because visual display of measured NO and NO₂ (or NO_x) concentrations was the "least common denominator" of data transfer among several NO/NO₂ analyzers tested.

Table 3-1. Identity and Schedule of Tests Conducted on Land Combustion LANCOM Series II Analyzers

Test Activity	Date Conducted
Laboratory Tests	
Linearity	May 24, 2000 a.m. ^a
Interrupted Sampling	May 22, p.m. - May 23, a.m.
Interferences	May 23, a.m.
Pressure Sensitivity	May 23, a.m.
Ambient Temperature	May 23, p.m.
Combustion Source Tests	
Gas Rangetop	May 24, p.m.
Gas Water Heater	May 24, p.m.
Diesel Generator–High RPM	May 24, p.m.
Diesel Generator–Idle	May 25, a.m.

^a Linearity tests were done May 22, a.m., but were repeated because of insufficient warm-up of the Land analyzers prior to the test.

Verification testing began with Land Combustion staff setting up and checking out their two analyzers in the laboratory at Battelle. Once vendor staff were satisfied with the operation of the analyzers, the laboratory tests were begun. These tests were carried out in the order specified in the test/QA plan.⁽¹⁾ However, the linearity and response time tests were redone at the end of the laboratory test sequence, as noted in Table 3-1, because of the vendor's concern that the analyzers were not fully warmed up prior to the initial tests. Upon completion of laboratory tests, the analyzers were moved to a nearby building where the combustion sources described below were set up, along with two chemiluminescent nitrogen oxides monitors which served as the reference analyzers. The combustion source tests were conducted indoors, with the gas combustion source exhausts vented through the roof of the test facility. The diesel engine was located immediately outside the wall of the test facility; sampling probes ran from the analyzers located indoors through the wall to the diesel exhaust duct. This arrangement assured that testing was not interrupted and that no bias in testing was introduced as a result of the weather. Sampling of source emissions began with the combustion source emitting the lowest NO_x concentration and proceeded to sources emitting progressively more NO_x. In all source sampling, the analyzers being tested sampled the same exhaust gas as did the reference analyzers. This was accomplished by inserting the LANCOM Series II analyzers' gas sampling probes into the same location in the exhaust duct as the reference analyzers' probe.

3.2 Laboratory Tests

The laboratory tests were designed to challenge the analyzers over their full nominal response ranges, which for the LANCOM Series II analyzers were 0 to 2,000 ppm for NO and 0 to 500 ppm for NO₂. These nominal ranges greatly exceed the actual NO or NO₂ concentrations likely to be emitted from most combustion sources. Nevertheless, the laboratory tests were aimed at quantifying the full range of performance of the analyzers.

Laboratory tests were conducted using certified standard gases for NO and NO₂, and a gas dilution system with flow calibrations traceable to the National Institute of Standards and Technology (NIST). The NO and NO₂ standards were diluted in high purity gases to produce a range of accurately known concentrations. The NO and NO₂ standards were EPA Protocol 1 gases, obtained from Scott Specialty Gases, of Troy, Michigan. As required by the EPA Protocol⁽³⁾ the concentration of these gas standards was established by the manufacturer within 1 percent accuracy using two independent analytical methods. The concentration of the NO standard (Scott Cylinder Number ALM 057210) was 3,925 ppm, and that of the NO₂ standard (Scott Cylinder Number ALM 031907) was 512 ppm. These standards were identical to NO and NO₂ standard cylinders used in the combustion source tests, which were confirmed near the end of the verification test by comparison with independent standards obtained from other suppliers.

The gas dilution system used was an Environics Model 4040 mass flow controlled diluter (Serial Number 2469). This diluter incorporated four separate mass flow controllers, having ranges of 10, 10, 1, and 0.1 lpm, respectively. This set of flow controllers allowed accurate dilution of gas standards over a very wide range of dilution ratios, by selection of the appropriate flow controllers. The mass flow calibrations of the controllers were checked against a NIST standard by the manufacturer prior to the verification test, and were programmed into the memory of the diluter. In verification testing, the Protocol Gas concentration, inlet port, desired output concentration, and desired output flow rate were entered by means of the keypad of the personal computer used to operate the diluter, and the diluter then set the required standard and diluent flow rates to produce the desired mixture. The 4040 diluter indicated on the computer display the actual concentration being produced, which in some cases differed very slightly from the nominal concentration requested. In all cases the actual concentration produced was recorded as the concentration provided to the analyzers undergoing testing. The 4040 diluter also provided warnings if a flow controller was being operated at less than 10% of its working range, i.e., in a flow region where flow control errors might be enhanced. Switching to another flow controller then minimized the uncertainties in the preparation of the standard dilutions.

Dilution gases used in the laboratory tests were Acid Rain CEM Zero Air and Zero Nitrogen from Scott Specialty Gases. These gases were certified to be of 99.9995% purity, and to have the following maximum content of specific impurities: SO₂ < 0.1 ppm, NO_x < 0.1 ppm, CO < 0.5 ppm, CO₂ < 1 ppm, total hydrocarbons < 0.1 ppm, and water < 5 ppm. In addition the nitrogen was certified to contain less than 0.5 ppm of oxygen, while the air was certified to contain 20 to 21% oxygen.

Laboratory testing was conducted primarily by supplying known gas mixtures to the analyzers from the Environics 4040 diluter, using a simple manifold that allowed the two analyzers to sample the same gas. The experimental setup is shown schematically in Figure 3-1. The manifold itself consisted of a 9.5-inch length of thin-walled 1-inch diameter 316 stainless steel tubing, with 1/4-inch tubing connections on each end. The manifold had three 1/4-inch diameter tubing side arms extending from it: two closely spaced tubes are the sampling points from which sample gas was withdrawn by the two analyzers, and the third provided a connection for a Magnehelic differential pressure gauge (± 15 inches of water range) that indicated the manifold pressure relative to the atmospheric pressure in the laboratory. Gas supplied to the manifold from the

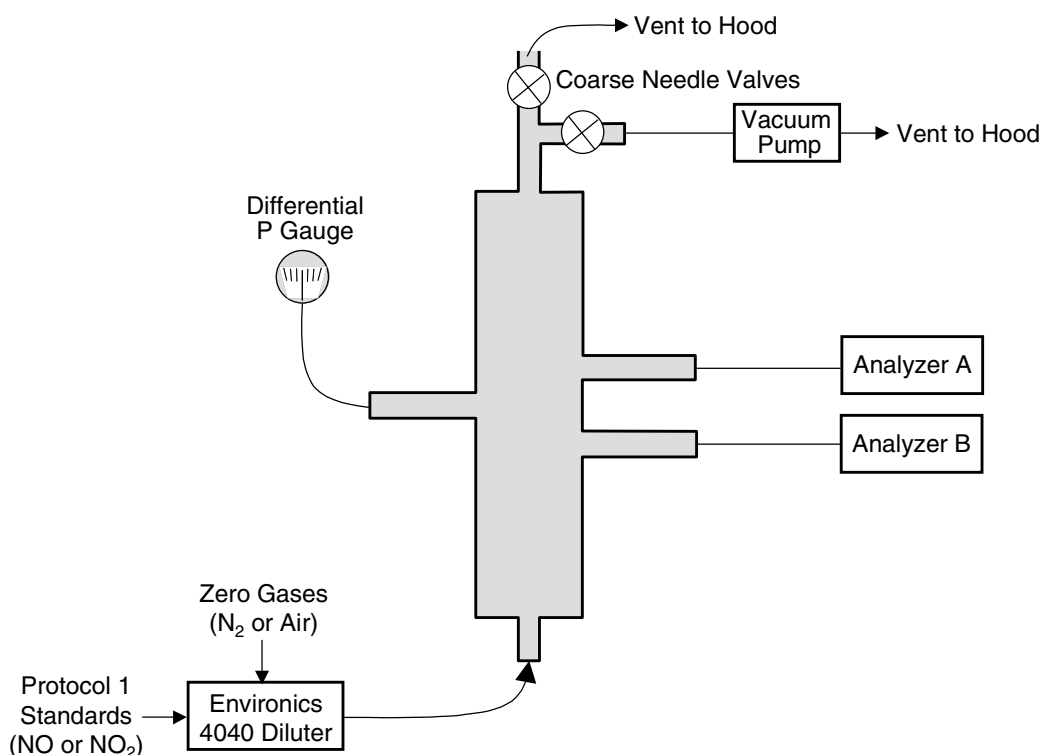


Figure 3-1. Manifold Test Setup

Environics 4040 diluter always exceeded by at least 0.5 lpm the total sample flow withdrawn by the two analyzers. The excess vented through a “T” connection on the exit of the manifold, and two coarse needle valves were connected to this “T,” as shown in Figure 3-1. One valve controlled the flow of gas out the normal exit of the manifold, and the other was connected to a small vacuum pump. Closing the former valve elevated the pressure in the manifold, and opening the latter valve reduced the pressure in the manifold. Adjustment of these two valves allowed close control of the manifold pressure within a target range of ± 10 inches of water, while maintaining excess flow of the gas mixtures to the manifold. The arrangement shown in Figure 3-1 was used in all laboratory tests, with the exception of interference testing. For most interference testing, gas standards of the appropriate concentrations were supplied directly to the manifold, without use of the Environics 4040 diluter.

Laboratory testing consisted of a series of separate tests evaluating different aspects of analyzer behavior. The procedures for those tests are described below, in the order in which the tests were actually conducted. The statistical procedures that were applied to the data from each test are presented in Chapter 5 of this report. Before starting the series of laboratory tests, the LANCOM Series II analyzers were calibrated with 1,000 ppm NO and with 100 ppm NO₂, prepared by diluting the EPA Protocol Gases using the Environics 4040 dilution system.

3.2.1 Linearity

Linearity testing consisted of a wide-range 21-point response check for NO and for NO₂. At the start of this check, the LANCOM Series II analyzers sampled the appropriate zero gas, and then an NO or NO₂ concentration near the respective nominal full scale of the analyzers (i.e., near 2,000 ppm NO or 500 ppm NO₂). The actual concentrations provided were 2,000 ppm NO and 512 ppm NO₂. The 21-point check then proceeded without any adjustments to the analyzers. The 21 points consisted of three replicates each at 10, 20, 40, 70, and 100% of the nominal range, in randomized order, and interspersed with six replicates of zero gas.⁽¹⁾ Following completion of all 21 points, the zero and 100 percent spans were repeated, also without adjustment of the analyzers. This entire procedure was performed for NO and then for NO₂. Throughout the linearity test, the analyzer indications of both NO and NO₂ concentrations were recorded, even though only NO or NO₂ was supplied to the analyzers. This procedure provided data to assess the cross-sensitivity to NO and NO₂.

3.2.2 Detection Limit

Data from zero gas and from 10% of full-scale points in the linearity test were used to establish the NO and NO₂ detection limits of the analyzers, using a statistical procedure defined in the test/QA plan.⁽¹⁾

3.2.3 Response Time

During the NO and NO₂ linearity tests, upon switching from zero gas to an NO or NO₂ concentration of 70% of the respective full scale (i.e., about 1,400 ppm NO or 350 ppm NO₂), the analyzers' responses were recorded at 10-second intervals until fully stabilized. These data were used to determine the response times for NO and for NO₂, defined as the time to reach 95% of final response after switching from zero gas to the calibration gas.

3.2.4 Interrupted Sampling

After the zero and span checks that completed the linearity test, the LANCOM Series II analyzers were shut down (i.e., their electrical power was turned off overnight), ending the first day of laboratory testing. The next morning the analyzers were powered up, and the same zero gas and span concentrations were run without adjustment of the analyzers. Comparison of the NO and NO₂ zero and span values before and after shutdown indicated the extent of zero and span drift resulting from the shutdown. Near full-scale NO and NO₂ levels (i.e., 2,000 ppm NO and 512 ppm NO₂) were used as the span values in this test.

3.2.5 Interferences

Following analyzer startup and completion of the interrupted sampling test, the second day of laboratory testing continued with interference testing. This test evaluated the response of the LANCOM Series II analyzers to species other than NO and NO₂. The potential interferants listed in Table 3-2 were supplied to the analyzers one at a time, and the NO and NO₂ readings of the

Table 3-2. Summary of Interference Tests Performed

Interferant	Interferant Concentration
CO	496 ppm
CO ₂	5.03%
SO ₂	501 ppm
NH ₃	494 ppm
Hydrocarbon Mixture ^a	465 ppm C ₁ , 94 ppm C ₂ , 46 ppm C ₃ + C ₄
SO ₂ and NO	451 ppm SO ₂ + 393 ppm NO

^a C₁ = methane; C₂ = ethane; and C₃ + C₄ = 23 ppm propane + 23 ppm n-butane.

analyzers were recorded. The potential interferants were used one at a time, except for a mixture of SO₂ and NO, which was intended to assess whether SO₂ in combination with NO produced a bias in NO response.

The CO, CO₂, SO₂, and NH₃ used in the interference test were all obtained as Certified Master Class Calibration Standards from Scott Technical Gases, at the concentrations indicated in Table 3-2. The indicated concentrations were certified by the manufacturer to be accurate within $\pm 2\%$, based on analysis. The CO, CO₂, and NH₃ were all in ultra-high purity (UHP) air, and the SO₂ was in UHP nitrogen. The SO₂/NO mixture listed in Table 3-2 was prepared by diluting the NO Protocol Gas with the SO₂ standard using the Environics 4040 diluter.

The hydrocarbon interferant listed in Table 3-2 was prepared at Battelle in UHP hydrocarbon-free air, starting from the pure compounds. Small quantities of methane, ethane, propane, and n-butane were injected into a cylinder that was then pressurized with UHP air. The required hydrocarbon concentrations were approximated by the preparation process, and then quantified by comparison with a NIST-traceable standard containing 1,020 ppm carbon (ppmC) in the form of propane. Using a gas chromatograph with a flame ionization detector (FID) the NIST-traceable standard was first analyzed. The resulting FID response factor (2,438 area units/ppmC) was then used to determine the concentrations of the components of the prepared hydrocarbon mixture. Two analyses of that mixture gave results of 463 and 467 ppm methane; the corresponding results for ethane were 93 and 95 ppm; for propane 22 and 23 ppm; and for n-butane 23 and 23 ppm.

In the interference test, each interferant in Table 3-2 was provided individually to the sampling manifold shown in Figure 3-1, at a flow in excess of that required by the two analyzers. Each period of sampling an interferant was preceded by a period of sampling the appropriate zero gas.

3.2.6 Pressure Sensitivity

The pressure sensitivity test was designed to quantify the dependence of analyzer response on the pressure in the sample gas source. By means of two valves at the downstream end of the sample manifold (Figure 3-1), the pressure in the manifold could be adjusted above or below the ambient room pressure, while supplying the manifold with a constant ppm level of NO or NO₂ from the Environics 4040 diluter. This capability was used to determine the effect of the sample gas pressure on the sample gas flow rate drawn by the analyzers, and on the NO and NO₂ response.

The dependence of sample flow rate on pressure was determined using an electronically timed bubble flow meter (Ultra Flow Primary Gas Flow Calibrator, Model 709, Serial No. 010928; SKC, Inc.). This flow meter was connected in line (i.e., inserted) into the sample flow path from the manifold to one of the commercial analyzers. Zero gas was supplied to the manifold at ambient pressure, and the analyzer's sample flow rate was measured with the bubble meter. The manifold pressure was then adjusted to -10 inches of water relative to the room, and the analyzer's flow rate was measured again. The manifold pressure was adjusted to +10 inches of water relative to the room, and the flow rate was measured again. The bubble meter was then moved to the sample inlet of the other commercial analyzer, and the flow measurements were repeated.

The dependence of NO and NO₂ response on pressure was determined by sampling the appropriate zero gas, and NO or NO₂ span gas levels of 1,400 ppm and 350 ppm respectively, at each of the same manifold pressures (room pressure, -10 inches, and +10 inches). This procedure was conducted simultaneously on both analyzers, first for NO at all three pressures, and then for NO₂ at all three pressures. The data at different pressures were used to assess zero and span drift resulting from the sample pressure differences.

3.2.7 Ambient Temperature

The purpose of the ambient temperature test was to quantify zero and span drift that may occur as the analyzers are subjected to different temperatures during operation. This test involved providing both analyzers with zero and span gases for NO and NO₂ (at the same span gas levels used in the pressure sensitivity test) at room, elevated, and reduced temperatures. A temperature range of about 7 to 40°C (45 to 105°F) was targeted in this test. The elevated temperature condition was achieved using a 1.43 m³ steel and glass laboratory chamber, heated using external heat lamps. The reduced temperature condition was achieved using a commercial laboratory refrigerated cabinet (Lab Research Products, Inc.).

The general procedure was to provide zero and span gas for NO, and then for NO₂, to both analyzers at room temperature, and then to place both analyzers and the sampling manifold into the heated chamber. Electrical and tubing connections were made through a small port in the lower wall of the chamber. A thermocouple readout was used to monitor the chamber temperature and room temperature, and the internal temperature indications of the analyzers themselves were monitored, when available. After 1 hour or more of stabilization in the heated chamber, the zero and span tests were repeated. The analyzers, manifold, and other connections were then

transferred to the refrigerator. After a stabilization period of 1 hour or more, the zero and span checks were repeated at the reduced temperature. The analyzers were returned to the laboratory bench; and, after a 1-hour stabilization period, the zero and span checks were repeated a final time.

3.3 Combustion Source Tests

3.3.1 Combustion Sources

Three combustion sources (a gas rangetop, a gas residential water heater, and a diesel engine) were used to generate NO_x emissions from less than 10 ppm to over 300 ppm. Emissions databases for two of these sources (rangetop and water heater) exist as a result of prior measurements, both of which have been published.^(4,5)

3.3.1.1 Rangetop

The low-NO_x source was a residential natural gas fired rangetop (KitchenAid Model 1340), equipped with four cast-iron burners, each with its own onboard natural gas and combustion air control systems. The burner used (front-left) had a fixed maximum firing rate of about 8 KBtu/hr.

The rangetop generates NO in the range of about 5 to 8 ppm, and NO₂ in the range of about 1 to 3 ppm. The database on this particular appliance was generated in an international study in which 15 different laboratories, including Battelle, measured its NO and NO₂ emissions.⁽⁴⁾

Rangetop NO_x emissions were diluted prior to measurement using a stainless-steel collection dome, fabricated according to specifications of the American National Standards Institute (ANSI Z21.1).⁽⁶⁾ For all tests, this dome was elevated to a fixed position 2 inches above the rangetop surface. Moreover, for each test, a standard “load” (pot) was positioned on the grate of the rangetop burner. This load was also designed according to ANSI Z21.1 specifications regarding size and material of construction (stainless steel). For each test, the load contained 5 pounds of room-temperature water.

The exit of the ANSI collection dome was modified to include seven horizontal sample-probe couplers. One of these couplers was 1/4-inch in size, three were 3/8-inch in size, and three were 1/2-inch in size. These were available to accommodate various sizes of vendor probes, and one reference probe, simultaneously during combustion-source sampling.

This low-NO_x combustion source was fired using “standard” natural gas, obtained from Praxair, Inc., which was certified to contain 90% methane, 3% ethane, and the balance nitrogen. This gaseous fuel contained no sulfur.

3.3.1.2 Water Heater

The medium-NO_x source was a residential natural gas-fired water heater (Ruud Model P40-7) of 40-gallon capacity. This water heater was equipped with one stamped-aluminum burner with its own onboard natural gas and combustion air control systems, which were operated according to

manufacturer's specifications. The burner had a fixed maximum firing rate of about 40 KBtu/hr. Gas flow to the water heater was monitored using a calibrated dry-gas meter.

The water heater generated NO emissions at approximately 80 ppm, and NO₂ in the range of 4 to 6 ppm. NO_x emissions dropped as the water temperature rose after ignition, stabilizing at the levels noted above. To assure constant operation of the water heater, a continuous draw of 3 gpm was maintained during all verification testing. A database on this particular appliance was generated in a national study in which six different laboratories measured its emissions, including Battelle.⁽⁵⁾

Water heater NO_x emissions were not diluted prior to measurement. The draft hood, integral to the appliance, was replaced with a 3-inch diameter, 7-inch long stainless-steel collar. The exit of this collar was modified to include five horizontal sample-probe couplers. One coupler was 1/4-inch in size, whereas the two other pairs were either 3/8- or 1/2-inch in size. Their purpose was to hold two vendor probes and one reference probe simultaneously during sampling. This medium-NO_x combustion source was fired on house natural gas, which contained odorant-level sulfur (4 ppm mercaptan).

3.3.1.3 Diesel Engine

The high-NO_x source was an industrial diesel 8 kW electric generator (Miller Bobcat 225D Plus), which had a Deutz Type ND-151 two-cylinder engine generating 41 KBtu/hr (16 horsepower). This device generates NO_x emissions over a range of about 200 to 330 ppm, depending on the load on the super-charged engine. High load (3,500 RPM) resulted in the lowest NO_x; idle resulted in the highest NO_x. At both conditions, about one-third of the NO_x was NO₂. Data on diesel generator emissions were generated in tests conducted in the two weeks prior to the start of the verification test.

NO_x emissions from this engine were not diluted prior to measurement. The 1-inch exhaust outlet of the engine, which is normally merely vented to the atmosphere, was fitted with a stack designed to meet the requirements of the EPA Method 5.⁽⁹⁾ The outlet was first expanded to 2 inches of 1.5-inch diameter copper tubing, then to 15 inches of 2-inch diameter copper tubing, and finally to 2 inches of 3-inch diameter copper tubing. The 3-inch diameter tubing was modified to include five horizontal sample-probe couplers. One of these couplers was 1/4-inch in size, two were 3/8-inch in size, and two were 1/2-inch in size. These couplers held the sample probes in place. The 3-inch tube was connected to a 3-inch stack extending through the roof of the test laboratory. This high-NO_x combustion source was fired on commercial diesel fuel, which, by specification, contains only 0.03 to 0.05 weight% sulfur.

3.3.2 Test Procedures

The procedures followed during combustion source testing consisted of those involved with the sampling systems, reference method, calibration gas supply, and the sources, as follows.

3.3.2.1 Sampling Systems

Prior to sampling, the Land Combustion representative inserted two of his product's probes into the exhaust duct of the rangetop, water heater, or diesel engine. The LANCOM Series II probes were fitted close to each other, sampling from a point within about 1/4 inch of the inlet of the reference analyzers' probe.

The reference analyzer probe consisted of an 18-inch long, 1/4-inch diameter stainless-steel tube, the upstream 2 inches of which were bent at a right angle for connection to a stainless steel bulkhead union in the wall of the exhaust duct. The inner end of the bulkhead union connected to a short length of 1/4-inch diameter stainless steel tube that extended into the center of the source exhaust duct. The LANCOM Series II analyzers were each operated with their own sample probe and sample transfer lines, and with the standard water trap and particulate and chemical filters. Based on the results of trial runs conducted before the verification tests, neither the reference sampling probe nor the reference sample-transfer lines were heated. Visible condensation of combustion-generated water did not occur. The reference analyzer moisture-removal system consisted of a simple condenser in an ice bath connected to the stainless steel probe by a 2-foot length of 1/4-inch diameter Teflon® tubing. The downstream end of the condenser was connected by a 3-foot length of 1/4-inch Teflon tubing to an inlet "tee" connected to both reference analyzers. The reference particulate-removal system consisted of a 47-millimeter in-line quartz fiber filter, which was used in sampling of the diesel emissions.

3.3.2.2 Reference Method

The reference method against which the vendor analyzers were compared was the ozone chemiluminescence method for NO that forms the basis of EPA Method 7E.⁽²⁾ The reference measurements were made using two Model 42-C source-level NO_x monitors (from Thermo Environmental Instruments) located on a wheeled cart positioned near the combustion sources. These monitors sampled from a common intake line, as described above. Both instruments use stainless steel converters maintained at 650°C (1,202°F) for reduction of NO₂ to NO for detection. The two reference analyzers were designated as Unit No. 100643 and 100647, respectively.

The reference analyzers were calibrated before and after combustion source tests using an Environics Series 2020 diluter (Serial No. 2108) and EPA Protocol 1 gases for NO and NO₂ (3,925 ppm, Cylinder No. ALM 15489, and 511.5 ppm, Cylinder No. AAL 5289, respectively; Scott Specialty Gases). The calibration procedure was specified in the test/QA plan, and required calibration at zero, 30%, 60%, and 100% of the applicable range value (i.e., 50, 100 or 1,000 ppm, depending on the emission source). Calibration results closest in time to the combustion source tests were used to establish scale factors applicable to the source test data. The conversion efficiency of the stainless steel converters was determined by calibrating with both NO and NO₂ on the applicable ranges, using the EPA Protocol 1 gases. The ratio of the linear regression slope of the NO₂ calibration to that of the NO calibration determined the NO₂ conversion efficiency. For the Land Combustion source tests, which took place on May 24 and 25, 2000, calibration results from May 24 were applied. Conversion efficiency values of 91.5% and 100% were found

for the two reference analyzers, and all reference data were corrected for these conversion efficiencies.

3.3.2.3 Calibration Gas Supply

Prior to the start of the combustion source tests, the LANCOM Series II analyzers were calibrated with NO and NO₂ concentrations of 100 ppm. In addition, before and after sampling of each combustion source, both the analyzers undergoing testing and the reference analyzers were supplied with zero gas and with standard NO and NO₂ mixtures at levels comparable to those expected from the source. To prepare these mixtures, Protocol 1 gases identical to those used in the laboratory testing were diluted using an Environics Series 2020 Multi-Gas Calibrator (Serial Number 2108). The same Acid Rain CEM zero gases were used for dilution and zeroing as were used in the laboratory tests. The pre- and post-test span values used with each combustion source are given in Table 3-3.

Table 3-3. Span Concentrations Provided Before and After Each Combustion Source

Source	NO Span Level (ppm)	NO ₂ Span Level (ppm)
Gas Rangetop	20	10
Gas Water Heater	100	15
Diesel–High RPM	200	50
Diesel–Idle	400	100

The pre- and post-test zero and span values were used to assess the drift in zero and span response of the tested analyzers caused by exposure to source emissions.

3.3.2.4 Operation of Sources

Verification testing was conducted with the combustion sources at or near steady-state in terms of NO_x emission. For the rangetop, steady-state was achieved after about 15 minutes, when the water began to boil. For the water heater, steady-state was achieved in about 15 minutes, when its water was fully heated. Because the water heater tank had a thermostat, cycling would have occurred had about 3 gpm of hot water not been continuously drained out of the tank.

For the diesel engine, steady-state was achieved in about 10 minutes of operation. The diesel was operated first at full speed (3,500 RPM) to achieve its lowest NO_x emissions. Prior to sampling the NO_x emissions at idle, the diesel engine was operated at idle for about 20 minutes to effectively “detune” its performance.

The order of operation of the combustion sources was (1) rangetop, (2) water heater, (3) diesel engine (high RPM), and (4) diesel engine (idle). This allowed the analyzers to be exposed to

continuously increasing NO and NO₂ levels, and avoided interference in low level measurements that might have resulted from prior exposure to high levels.

Sampling of each combustion source consisted of obtaining nine separate measurements of the source emissions. After sampling of pre-test zero and span gases provided from the calibration source, and with both the reference and vendor analyzers sampling the source emissions, the Land Combustion operator indicated when he was ready to take the first set of readings (a set of readings consisting of the NO and NO₂ response on both Units A and B). At that time the Battelle operator of the reference analyzers also took corresponding readings. The analyzers undergoing testing were then disconnected from the source, and allowed to sample room air until readings dropped well below the source emissions levels. The analyzers were then reconnected to the source, and after stabilizing another set of readings was taken. There was no requirement that analyzer readings drop fully to zero between source measurements. This process was repeated until a total of nine readings had been obtained with both the vendor and reference analyzers. The same zero and span gases were then sampled again before moving to the next combustion source.

The last operation in the combustion source testing involved continuous sampling of the diesel engine emissions for a full hour with no intervals of room air sampling. Data were recorded for both reference and vendor analyzers at 1-minute intervals throughout that hour of measurement. This extended sampling was conducted only after nine sequential sets of readings had been obtained from all the combustion sources by the procedure described above. Results from this extended sampling were used to determine the measurement stability of the LANCOM Series II analyzers.

Chapter 4

Quality Assurance/Quality Control

Quality control (QC) procedures were performed in accordance with the quality management plan (QMP) for the AMS Center⁽⁷⁾ and the test/QA plan⁽¹⁾ for this verification test.

4.1 Data Review and Validation

Test data were reviewed and approved according to the AMS Center QMP, the test/QA plan, and Battelle's one-over-one approval policy. The Verification Testing Leader reviewed the raw data and data sheets that were generated each day. Laboratory record notebooks were also signed and dated by testing staff and reviewed by the Verification Testing Leader.

Other data review focused upon the compliance of the reference analyzer data with the quality requirements of Method 7E. The purpose of validating reference data was to ensure usability for the purposes of comparison with the demonstration technologies. The results of the review of the reference analyzer data quality are shown in Table 4-1. The data generated by the reference analyzers were used as a baseline to assess the performance of the technologies for NO/NO₂ analysis.

4.2 Deviations from the Test/QA Plan

During the physical set up of the verification test, deviations from the test/QA plan were made to better accommodate differences in vendor equipment and other changes or improvements. Any deviation required the approval signature of Battelle's Verification Testing Leader and Pilot Manager. A planned deviation form was used for documentation and approval of the following changes:

1. The order of testing was changed in the pressure sensitivity test to require fewer plumbing changes in conducting the test.
2. The order of the ambient temperature test was changed to maximize the detection of any temperature effect.
3. The concentrations used in the mixture of SO₂ and NO for the interference test were changed slightly.
4. For better accuracy, the oxygen sensor used during combustion source tests was checked by comparison to an independent paramagnetic O₂ sensor, rather than to a wet chemical measurement.
5. Single points (rather than triplicate points) were run at each calibration level in calibrating the reference analyzers, in accord with Method 7E.

Table 4-1. Results of QC Procedures for Reference Analyzers for Testing of Land Combustion LANCOM Series II Analyzers

NO ₂ conversion efficiency (Unit 100643)	91.5%																																								
NO ₂ conversion efficiency (Unit 100647)	100%																																								
Calibration of reference method using four points at 0, 30, 60, 100% for NO	Meets criteria (r ² = 0.9999)																																								
Calibration of reference method using four points at 0, 30, 60, 100% for NO ₂	Meets criteria (r ² = 0.9999)																																								
Calibrations (100 ppm range)	Meet ± 2% requirement (relative to span)	<table><tr><th colspan="2">Unit 100643</th><th colspan="2">Unit 100647</th></tr><tr><th colspan="2">NO</th><th colspan="2">NO</th></tr><tr><th>Error, % of Span</th><th>at % of Scale</th><th>Error, % of Span</th><th>at % of Scale</th></tr><tr><td>1.0</td><td>30</td><td>0.9</td><td>30</td></tr><tr><td>0.4</td><td>60</td><td>0.3</td><td>60</td></tr><tr><th colspan="2">NO₂</th><th colspan="2">NO₂</th></tr><tr><th>Error, % of Span</th><th>at % of Scale</th><th>Error, % of Span</th><th>at % of Scale</th></tr><tr><td>0.5</td><td>30</td><td>0.5</td><td>30</td></tr><tr><td>0.1</td><td>60</td><td>0.2</td><td>60</td></tr></table>				Unit 100643		Unit 100647		NO		NO		Error, % of Span	at % of Scale	Error, % of Span	at % of Scale	1.0	30	0.9	30	0.4	60	0.3	60	NO ₂		NO ₂		Error, % of Span	at % of Scale	Error, % of Span	at % of Scale	0.5	30	0.5	30	0.1	60	0.2	60
Unit 100643		Unit 100647																																							
NO		NO																																							
Error, % of Span	at % of Scale	Error, % of Span	at % of Scale																																						
1.0	30	0.9	30																																						
0.4	60	0.3	60																																						
NO ₂		NO ₂																																							
Error, % of Span	at % of Scale	Error, % of Span	at % of Scale																																						
0.5	30	0.5	30																																						
0.1	60	0.2	60																																						
Zero drift	Meets ± 3% requirement (relative to span) on all combustion sources																																								
Span drift	Meets ± 3% requirement (relative to span) on all combustion sources																																								
Interference check	< ± 2% (no interference response observed)																																								

4.3 Calibration of Laboratory Equipment

Equipment used in the verification test required calibration before use or verification of the manufacturer's calibrations. Some auxiliary devices were obtained with calibrations from Battelle's Instrument Laboratory. Equipment types and calibration dates are listed in Table 4-2. For key equipment items, the calibrations listed include performance evaluation audits (see Section 4.5.2). Documentation of calibration of the following equipment was maintained in the test file.

Table 4-2. Equipment Type and Calibration Date

Equipment Type	Use	Calibration/PE Date
Gas Dilution System Environics Model 4040 (Serial Number 2469)	Lab tests	3/9/00; 5/9/00
Gas Dilution System Environics Model 2020 (Serial Number 2108)	Source tests	3/20/00; 5/9/00
Fluke Digital Thermometer (LN-570068)	Ambient temperature test	10/15/99; 5/26/00
Servomex 570A Analyzer (X-44058)	Flue gas O ₂	11/22/99; 5/18/00
Dwyer Magnahelic Pressure Gauge	Pressure sensitivity test	4/7/00
Doric Trendicator 410A Thermocouple Temperature Sensor (Serial Number 331513)	Flue gas temperature	8/5/99; 5/26/00
American Meter DTM 115 Dry Gas Meter (Serial Number 89P124205)	Gas flow measurement	4/17/00

4.4 Standard Certifications

Standard or certified gases were used in all verification tests, and certifications or analytical data were kept on file to document the traceability of the following standards:

- EPA Protocol Gas Nitrogen Dioxide
- EPA Protocol Gas Nitric Oxide
- Certified Master Class Calibration Standard Sulfur Dioxide
- Certified Master Class Calibration Standard Carbon Dioxide
- Certified Master Class Calibration Standard Ammonia
- Certified Master Class Calibration Standard Carbon Monoxide
- Nitrogen Acid Rain CEM Zero

-
- Acid Rain CEM Zero Air
 - Battelle-Prepared Organics Mixture.

All other QC documentation and raw data for the verification test are located in the test file at Battelle, to be retained for 7 years and made available for review if requested.

4.5 Performance System Audits

Three internal audits were conducted during verification testing. A technical systems audit was conducted to assess the physical setup of the test, a performance evaluation audit was conducted to evaluate the accuracy of the measurement system, and an audit of data quality was conducted on 10% of all data generated during the verification test. A summary of the results of these audits is provided below.

4.5.1 Technical Systems Audits

A technical systems audit (TSA) was conducted on April 18, 2000, (laboratory testing) and May 17 and 18, 2000, (source testing) for the NO/NO₂ verification tests conducted in early 2000. The TSA was performed by the Battelle's Quality Manager as specified in the AMS Center Quality Management Plan (QMP). The TSA ensures that the verification tests are conducted according to the test/QA plan⁽¹⁾ and all activities associated with the tests are in compliance with the AMS Center QMP⁽⁷⁾. All findings noted during the TSA on the above dates were documented and submitted to the Verification Testing Leader for correction. The corrections were documented by the Verification Testing Leader and reviewed by Battelle's Quality Manager and Center Manager. None of the findings adversely affected the quality or outcome of this verification test and were resolved to the satisfaction of the Battelle Quality Manager. The records concerning the TSA are permanently stored with the Battelle Quality Manager.

4.5.2 Performance Evaluation Audit

The performance evaluation audit was a quantitative audit in which measurement standards were independently obtained and compared with those used in the verification test to evaluate the accuracy of the measurement system. That assessment was conducted by Battelle testing staff on May 26, 2000, and the results were reviewed by independent QA personnel.

The most important performance evaluation (PE) audit was of the standards used for the reference measurements in source testing. The PE standards were NO and NO₂ calibration gases independent of the test calibration standards that contained certified concentrations of NO and NO₂. Accuracy of the reference analyzers was determined by comparing the measured NO/NO₂ concentrations using the verification test standards with those obtained using the certified PE standards. Percent difference was used to quantify the accuracy of the results. The PE sample for NO was an EPA Protocol Gas having a concentration (3,988 ppm) nearly the same as the NO standard used in verification testing, but purchased from a different commercial supplier (Matheson Gas Products). The PE standard for NO₂ was a similar commercial standard of 463 ppm NO₂ in air, also from Matheson. Table 4-3 summarizes the NO/NO₂ reference standard

performance evaluation results. Included in this table are the performance acceptance ranges and the certified gas concentration values. The acceptance ranges are guidelines established by the provider of the PE materials to gauge acceptable analytical results.

Table 4-3. Performance Evaluation Results on NO/NO₂ Standards

Reference Analyzer	Standard	Reading on Diluted Standard	Apparent Concentration^a	Percent Difference^b	Acceptance Limits
NO in N₂					
Unit 100643	(ppm)				
Test Std	3,925	98.8 ppm	3,917 ppm	0.2%	±2%
PE Std	3,988	100.6 ppm			
NO in N₂					
Unit 100647	(ppm)				
Test Std	3,925	99.6 ppm	3,917 ppm	0.2%	±2%
PE Std	3,988	101.4 ppm			
NO₂ in Air					
Unit 100643	(ppm)				
Test Std	511.5	44.2 ppm	482 ppm	5.8%	±5%
PE Std	463	42.5 ppm			
NO₂ in Air					
Unit 100647	(ppm)				
Test Std	511.5	49.6 ppm	471 ppm	7.9%	±5%
PE Std	463	48.8 ppm			

^a Concentration of Test Standard indicated by comparison to the Performance Evaluation Standard; i.e., Apparent Concentration = (Test Std. Reading/PE Std. Reading) × PE Std. Conc.; e.g., Apparent Concentration = 98.8/100.6 × 3,988 ppm = 3,917 ppm.

^b Percent difference of Apparent Concentration relative to Test Standard concentration; e.g., percent difference = $\frac{3,925 \text{ ppm} - 3,917 \text{ ppm}}{3,925 \text{ ppm}} \times 100 = 0.2\%$.

Table 4-3 shows that the PE audit confirmed the concentration of the Scott 3,925 ppm NO test standard almost exactly: the apparent test standard concentration was within 0.2% of the test standard's nominal value. On the other hand, the PE audit results for the Scott 511.5 ppm NO₂ standard were not as close. The comparison to the Matheson PE standard indicated that the 511.5 ppm NO₂ Scott standard was only about 480 ppm, a difference of about 7% from its nominal value. This result suggests an error in the Scott test standard for NO₂. However, a separate line of evidence indicates that the Matheson PE standard is more likely in error. Specifically, conversion efficiency checks on the reference analyzers (performed by comparing their responses to the

Scott NO and NO₂ standards) consistently showed the efficiency of the converter in 42-C Unit 100647 to be very close to 100%. This finding could not occur if the concentration of the NO₂ standard were low. That is, a conversion efficiency of 100% indicates agreement between the NO standard and the NO₂ standard; and, as shown in Table 4-3, the NO standard is confirmed by the PE comparison. Thus, the likelihood is that the Matheson PE standard was in fact somewhat higher in concentration than its nominal 463 ppm value.

PE audits were also done on the O₂ sensor used for flue gas measurements, and on the temperature indicators used for ambient and flue gas measurements. The PE standard for O₂ was an independent paramagnetic sensor, and for temperature was a certified mercury-in-glass thermometer. The O₂ comparison was conducted during sampling of diesel exhaust; the temperature comparisons were conducted at room temperature. The results of those audits are shown in Table 4-4, and indicate close agreement of the test equipment with the PE standards.

Table 4-4. Performance Evaluation Results on O₂ and Temperature Measuring Equipment

Analyzer	Reading	Difference	Acceptance Limits
Servomex 570A O ₂	18.9% O ₂	0% O ₂	—
PE Standard ^a	18.9% O ₂		
Fluke Digital Thermometer	22.1 °C	0.1 °C	2% absolute T
PE Standard ^a	22 °C		
Doric 410A Temp. Sensor	24.8 °C	0.2 °C	2% absolute T
PE Standard ^b	25.0 °C	0.2 °C	

^a Independent paramagnetic O₂ analyzer.

^b Certified mercury-in-glass thermometer.

4.5.3 Audit of Data Quality

The audit of data quality is a qualitative and quantitative audit in which data and data handling are reviewed and data quality and data usability are assessed. Audits of data quality are used to validate data at the frequency of 10% and are documented in the data audit report. The goal of an audit of data quality is to determine the usability of test results for reporting technology performance, as defined during the design process. Validated data are reported in the ETV verification reports and ETV verification statement along with any limitations on the data and recommendations for limitations on data usability.

The Battelle Quality Manager for the verification test audited 10% of the raw data. Test data sheets and laboratory record books were reviewed, and statistical calculations and other algorithms were verified. Calculations that were used to assess the four-point calibration of the reference method were also verified to be correct. In addition, data presented in the verification report and statement were audited to ensure accurate transcription.

Chapter 5

Statistical Methods

5.1 Laboratory Tests

The analyzer performance characteristics were quantified on the basis of statistical comparisons of the test data. This process began by converting the spreadsheet files that resulted from the data acquisition process into data files suitable for evaluation with Statistical Analysis System (SAS) software. The following statistical procedures were used to make those comparisons.

5.1.1 Linearity

Linearity was assessed by linear regression with the calibration concentration as the independent variable and the analyzer response as the dependent variable. Separate assessments were carried out for each Land Combustion analyzer. The calibration model used was

$$Y_c = h(c) + error_c$$

where Y_c is the analyzer's response to a challenge concentration c , $h(c)$ is a linear calibration curve, and the error term was assumed to be normally distributed. (If the variability is not constant throughout the range of concentrations then weighting in the linear regression is appropriate. It is often the case that the variability increases as the true concentration increases.) The variability (σ_c) of the measured concentration values (c) was modeled by the following relationship,

$$\sigma_c^2 = \alpha + kc^\beta$$

where α , k , and β are constants to be estimated from the data. After determining the relationship between the mean and variability, appropriate weighting was determined as the reciprocal of the variance.

$$weight = w_c = \frac{1}{\sigma_c^2}$$

The form of the linear regression model fitted was $h(c) = \alpha_o + \alpha_1 c$. In the concentration sub-region where the linear calibration model provides a valid representation of the concentration-response relation, concentration values were calculated from the estimated calibration curve using the relation

$$\hat{c} = \hat{h}^{-1}(Y_c) = \frac{Y_c - \hat{\alpha}_o}{\hat{\alpha}_1}$$

A test for departure from linearity was carried out by comparing the residual mean square

$$\frac{1}{4} \sum_{i=1}^6 (\bar{Y}_{c_i} - \alpha_o - \alpha_1 c_i)^2 n_{c_i} w_{c_i}$$

to an F-distribution with $6 - 2 = 4$ numerator degrees of freedom.

\bar{Y}_{c_i} is the average of the n_{c_i} analyzer responses at the i^{th} calibration concentration, c_i . The regression relation was fitted to the individual responses; however, only the deviation about the sample mean analyzer responses at each calibration concentration provide information about goodness-of-fit.

$$\sum_{i=1}^n \sum_{j=1}^{n_{c_i}} (Y_{cij} - \alpha_o - \alpha_1 c_i)^2 w_{ci} = \sum_{i=1}^n \sum_{j=1}^{n_{c_i}} (Y_{ci} - \bar{Y}_{c_i})^2 w_{ci} + \sum_{i=1}^n (\bar{Y}_{c_i} - \alpha_o - \alpha_1 c_i)^2 n_{c_i} w_{ci}$$

The first summation on the right side of the equation provides information only about response variability. The second summation provides all the information about goodness-of-fit to the straight-line calibration model. This is the statistic that is used for the goodness-of-fit test.

5.1.2 Detection Limit

Limit of detection (LOD) is defined as the smallest true concentration at which an analyzer's expected response exceeds the calibration curve at zero concentration by three times the standard deviation of the analyzer's zero reading, i.e., $\alpha_o + 3 \sigma_o$, if the linear relation is valid down to zero. The LOD may then be determined by

$$LOD = \frac{[(\alpha_o + 3\sigma_o) - \alpha_o]}{\alpha_1} = \frac{3\sigma_o}{\alpha_1}$$

where σ_o is the estimated standard deviation at zero concentration. The LOD is estimated as the $LOD = 3\hat{\sigma}_o / \hat{\alpha}_1$. standard error of the estimated detection limit is approximately

$$\hat{SE} (\hat{LOD}) \cong \hat{LOD} \sqrt{\frac{1}{2(n-1)} + \left(\frac{SE(\hat{a}_1)}{\hat{a}_1} \right)^2}$$

Note that the validity of the detection limit estimate and its standard error depends on the validity of the assumption that the fitted linear calibration model accurately represents the response down to zero concentration.

5.1.3 Response Time

The response time of the analyzers to a step change in analyte concentration was calculated by determining the total change in response due to the step change in concentration, and then determining the point in time when 95% of that change was achieved. Using data taken every 10 seconds, the following calculation was carried out:

$$\text{Total Response} = R_c - R_z$$

where R_c is the final response of the analyzer to the calibration gas and R_z is the final response of the analyzer to the zero gas. The analyzer response that indicates the response time then is:

$$\text{Response}_{95\%} = 0.95(\text{Total Response}) + R_z.$$

The point in time at which this response occurs was determined by inspecting the response/time data, linearly interpolating between two observed time points, as necessary. The response time was calculated as:

$$RT = \text{Time}_{95\%} - \text{Time}_I,$$

where $\text{Time}_{95\%}$ is the time at which Response_{RT} occurred and Time_I is the time at which the span gas was substituted for the zero gas. Since only one measurement was made, the precision of the response time was not determined.

5.1.4 Interrupted Sampling

The effect of interrupted sampling is the arithmetic difference between the zero data and between the span data obtained before and after the test. Differences are stated as ppm. No estimate was made of the precision of the observed differences.

5.1.5 Interferences

Interference is reported as both the absolute response (in ppm) to an interferant level, and as the sensitivity of the analyzer to the interferant species, relative to its sensitivity to NO or NO₂. The

relative sensitivity is defined as the ratio of the observed NO/NO₂/NO_x response of the analyzer to the actual concentration of the interferant. For example, an analyzer that measures NO is challenged with 500 ppm of CO, resulting in an absolute difference in reading of 1 ppm (as NO). The relative sensitivity of the analyzer is thus 1 ppm/500 ppm = 0.2%. The precision of the interference results was not estimated from the data obtained, since only one measurement was made for each interferant.

5.1.6 Pressure Sensitivity

At each of ambient pressure, reduced pressure (-10 inches of water), and increased pressure (+10 inches of water), the analyzer flow rate, the response on zero gas, and the response on span gas were measured for each analyzer. Variability in zero and span responses for reduced and increased pressures was assumed to be the same as the variability at ambient pressure. The variability determined in the linearity test was used for this analysis. The duct pressure effects on analyzer flow rates and response were assessed by separate linear regression trend analyses for flow rate and for response. The precision of the pressure effects on zero concentration response and on span gas response was estimated based on the variability observed in the linearity test. Statistical significance of the trends across duct pressures was determined by comparing the estimated trends to their estimated standard errors, based on two-tailed t-tests:

$$t = \hat{\beta} / (0.040825 \hat{\sigma}(c)) \text{ for the zero concentration test}$$

$$t = \hat{\beta} / (0.07071 \hat{\sigma}(c)) \text{ for the span concentration test}$$

5.1.7 Ambient Temperature

The statistical analysis for evaluation of ambient temperature effects was similar to that used for assessing the pressure sensitivity. At room temperature, low temperature, and high temperature for each analyzer the response on zero gas and the response on span gas were observed. Variability for low and for high temperatures was assumed to be the same as variability at room temperature. The ambient temperature effects on zero and span readings were assessed by trend analysis for response with temperature, using separate linear regression analyses for the zero and for the span data. Precision of the ambient temperature effect was estimated based on the variability observed in the linearity test. Statistical significance of the trends across temperatures was determined by comparing the estimated trends to their estimated standard errors, based on two-tailed t-tests:

$$t = \hat{\beta} / (0.01723 \hat{\sigma}(c)) \text{ for the zero concentration test}$$

$$t = \hat{\beta} / (0.024363 \hat{\sigma}(c)) \text{ for the span concentration test}$$

5.2 Combustion Source Tests

5.2.1 Accuracy

The relative accuracy (RA) of the analyzers with respect to the reference method is expressed as:

$$RA = \frac{|\bar{d}| + t_{n-1}^{\alpha} \frac{S_d}{\sqrt{n}}}{\bar{x}} \times 100\%$$

where d refers to the difference between the average of the two reference analyzers and one of the tested units and x corresponds to the average of the two reference analyzer values. S_d denotes the sample standard deviation of the differences, based on $n = 9$ samples, while t_{n-1}^{α} is the t value for the $100(1 - \alpha)$ th percentile of the distribution with $n - 1$ degrees of freedom. The relative accuracy was determined for an α value of 0.025 (i.e., 97.5% confidence level, one-tailed). The RA calculated in this way can be determined as an upper confidence bound for the relative bias of the analyzer $|\bar{d}|/\bar{x}$, where the bar indicates the average value of the differences or of the reference values.

Assuming that the reference method variation is due only to the variation in the output source and the true bias between the test and reference methods is close to zero, an approximate standard error for RA is

$$\hat{SE} \cong \frac{S_d}{\sqrt{n} \bar{x}} \sqrt{0.3634 + \left(t_{n-1}^{\alpha}\right)^2 \frac{1}{2(n-1)}} \times 100\%$$

5.2.2 Zero/Span Drift

Statistical procedures for assessing zero and span drift were similar to those used to assess interrupted sampling. Zero (span) drift was calculated as the arithmetic difference between zero (span) values obtained before and after sampling of each combustion source. The same calculation was also made using zero and span values obtained before and after the linearity and ambient temperature tests. No estimate was made of the precision of the zero and span drift values.

5.2.3 Measurement Stability

The temporal stability of analyzer response in extended sampling from a combustion source was assessed by means of a trend analysis on 60 minutes of data obtained continuously using the diesel generator as the source. The existence of a difference in trend between the test unit and the average of the reference units was assessed by fitting a linear regression line with the difference between the measured concentration for a test unit and the average of the reference units as the dependent variable, and time as the independent variable. Subtracting the average reference unit

values adjusts for variation in the source output. The slope and the standard error of the slope are reported. The null hypothesis that the slope of the trend line on the difference is zero was tested using a one-sample two-tailed t-test with $n - 2 = 58$ degrees of freedom.

5.2.4 Inter-Unit Repeatability

The purpose of this comparison was to determine if any significant differences in performance exist between two identical analyzers operating side by side. In tests in which analyzer performance was verified by comparison with data from the reference method, the two identical units of each type of analyzer were compared to one another using matched pairs t-test comparisons. In tests in which no reference method data were obtained (e.g., linearity test), the two LANCOM Series II analyzer units were compared using statistical tests of difference. For example, the slopes of the calibration lines determined in the linearity test, and the detection limits determined from those test data, were compared. Inter-unit repeatability was assessed for the linearity, detection limit, accuracy, and measurement stability tests.

For the linearity test, the intercepts and slopes of the two units were compared to one another by two-sample t-tests using the pooled standard error, with combined degrees of freedom the sum of the individual degrees of freedom.

For the detection limit test, the detection limits of the two units were compared to one another by two-sample t-tests using the pooled standard error with 10 degrees of freedom (the sum of the individual degrees of freedom).

For the relative accuracy test, repeatability was assessed with a matched-pairs two-tailed t-test with $n - 1 = 8$ degrees of freedom.

For the measurement stability test, the existence of differences in trends between the two units was assessed by fitting a linear regression to the paired differences between the units. The null hypothesis that the slope of the trend line on the paired differences is zero was tested using a matched-pairs t-test with $n - 2 = 58$ degrees of freedom.

5.2.5 Data Completeness

Data completeness was calculated as the percentage of possible data recovered from an analyzer in a test; the ratio of the actual to the possible number of data points, converted to a percentage, i.e.,

$$\text{Data Completeness} = (N_a)/(N_p) \times 100\%,$$

where N_a is the number of actual and N_p the number of planned data points.

Chapter 6 Test Results

6.1 Laboratory Tests

6.1.1 Linearity

Tables 6-1a and b list the data obtained in the linearity tests for NO and NO₂, respectively. The response of both the NO and NO₂ sensors in each analyzer is shown in those tables.

Table 6-2 shows the results of the linear calibration curve fits for each unit and each analyte, based on the data shown in Tables 6-1a and b.

Table 6-1a. Data from NO Linearity Test of Land Combustion LANCOM Series II Analyzers

Reading	Actual NO (ppm)	Unit A NO (ppm)	Unit A NO ₂ (ppm)	Unit B NO (ppm)	Unit B NO ₂ (ppm)
1	0	2	0	3	0
2	2000	1998	7	1978	10
3	200	197	1	202	1
4	800	802	2	802	2
5	0	2	0	3	0
6	1400	1406	3	1398	4
7	420	423	1	423	1
8	200	197	1	201	0
9	0	2	0	2	0
10	420	420	1	421	0
11	800	808	1	808	1
12	1400	1416	3	1408	3
13	0	3	0	4	0
14	2000	2009	4	1988	4
15	1400	1416	3	1409	3
16	800	813	2	815	1
17	0	4	0	4	0
18	420	421	0	422	0
19	200	197	0	200	0
20	2000	2020	4	1995	3
21	0	3	0	4	0

Table 6-1b. Data from NO₂ Linearity Test of Land Combustion LANCOM Series II Analyzers

Number	Actual NO ₂ (ppm)	Unit A NO (ppm)	Unit A NO ₂ (ppm)	Unit B NO (ppm)	Unit B NO ₂ (ppm)
1	0	0	0	0	0
2	512	10	507	9	496
3	50	0	52	0	52
4	200	2	199	2	199
5	0	2	1	0	0
6	350	8	347	7	341
7	105	1	106	1	105
8	50	1	51	0	50
9	0	2	1	0	0
10	105	1	105	1	103
11	200	4	199	3	196
12	350	11	349	10	343
13	0	3	1	1	0
14	512	20	511	16	501
15	350	12	348	10	341
16	200	7	202	6	199
17	0	4	2	2	1
18	105	2	105	2	103
19	50	3	51	1	50
20	512	23	512	19	501
21	0	4	2	2	1

Table 6-2. Statistical Results for Test of Linearity

Linear Regression	Unit A		Unit B	
	NO	NO ₂	NO	NO ₂
Intercept (ppm) (Std Err)	1.526 (0.711)	1.243 (0.244)	2.888 (0.496)	0.564 (0.248)
Slope (Std Err)	1.000 (0.003)	0.993 (0.002)	0.999 (0.002)	0.977 (0.002)
r ²	0.9998	1.0000	0.9999	0.9999

The results in Table 6-2 show that the NO response of both units of the LANCOM Series II analyzers was linear over the tested range of 0 to 2,000 ppm. The regression slopes are essentially 1.0, and the r² values are 0.9998 or higher.

The NO₂ linearity results in Table 6-2 show that, over the tested range of up to 512 ppm NO₂, the LANCOM Unit A analyzer gave highly linear response, whereas the B unit exhibited a slightly low regression slope of about 0.98. Inspection of the NO₂ linearity data shows that the slope of the Unit B NO₂ response is close to 1.0 up to about 250 ppm, but that the response is low by about 2.5% at the 350 and 512 ppm NO₂ concentrations. This result is probably due to the older NO₂ sensor used in the LANCOM Unit B, as compared to that used in Unit A.

The data in Tables 6-1a and 6-1b also indicate the extent of cross-sensitivity of the LANCOM Series II NO and NO₂ sensors. Regression of the NO₂ responses in the NO linearity test (Table 6-1a) gives the following results:

$$\begin{aligned}\text{Unit A NO}_2 &= 0.0024 \times (\text{NO, ppm}) - 0.08 \text{ ppm, with } r^2 = 0.870, \text{ and} \\ \text{Unit B NO}_2 &= 0.0028 \times (\text{NO, ppm}) - 0.34 \text{ ppm, with } r^2 = 0.701.\end{aligned}$$

These results indicate a very slight response of the LANCOM Series II NO₂ sensors to NO, amounting to about 0.3% of the NO level present.

Similarly, regression of the LANCOM Series II NO responses in the NO₂ linearity test (Table 6-1b) gives the following results:

$$\begin{aligned}\text{Unit A NO} &= 0.030 \times (\text{NO}_2, \text{ ppm}) + 0.51 \text{ ppm, with } r^2 = 0.755, \text{ and} \\ \text{Unit B NO} &= 0.027 \times (\text{NO}_2, \text{ ppm}) - 0.39 \text{ ppm, with } r^2 = 0.841.\end{aligned}$$

These results indicate a small response of the LANCOM Series II NO sensors to NO₂, amounting to about 3% of the NO₂ level present.

6.1.2 Detection Limit

Table 6-3 shows the estimated detection limits for each test unit and each analyte, determined from the data obtained in the linearity test. These detection limits apply to the calibrations conducted over a 0 to 2,000 ppm range for NO (Table 6-1a) and a 0 to 512 ppm range for NO₂ (Table 6-1b).

Table 6-3. Estimated Detection Limits for Land Combustion LANCOM Series II Analyzers^a

	Unit A		Unit B	
	NO	NO ₂	NO	NO ₂
Estimated Detection Limit (ppm)	2.45	2.28	2.45	1.59
(Standard Error) (ppm)	(0.78)	(0.72)	(0.78)	(0.50)

^a Results are based on calibrations over 0-2,000 ppm range for NO and 0-512 ppm range for NO₂.

Table 6-3 displays the estimated detection limits, and their standard errors for NO and NO₂, separately for each LANCOM Series II analyzer. NO detection limits of about 2.5 ppm, and NO₂ detection limits of 1.5 to 2.3 ppm, are indicated. It must be stressed that these detection limits are based on the zero gas responses, interspersed with sampling of high levels of NO and NO₂ in the linearity tests. The vendor indicates that, under normal field use, the operator would zero the analyzer every 20 minutes, thus eliminating any long-term drift and maintaining 1 ppm detection limits.

6.1.3 Response Time

Table 6-4 lists the data obtained in the response time test of the LANCOM Series II analyzers. Table 6-5 shows the response times of the analyzers to a step change in analyte concentration, based on the data shown in Table 6-4.

Table 6-5 shows that the NO response times were quite similar for Units A and B, at 35 and 39 seconds. The NO₂ response times were substantially longer, and the agreement between Units A and B not as close (77 vs. 90 seconds). The slightly slower response of Unit B for NO₂ may be a result of the older NO₂ sensor used in that unit.

6.1.4 Interrupted Sampling

Table 6-6 shows the zero and span data resulting from the interrupted sampling test, and Table 6-7 shows the differences (pre- minus post-) of the zero and span values. Span concentrations of 2,000 ppm NO and 512 ppm NO₂ were used for this test.

Table 6-7 shows that changes in zero readings for both NO and NO₂ were 2 ppm or less as a result of the overnight shutdown. The LANCOM Series II analyzers also showed only small changes as a result of the shutdown. The maximum change observed in the NO span response was about 3% of the 2,000 ppm NO span value, and the maximum change in the NO₂ span response was about 2% of the 512 ppm NO₂ span value. These small changes in readings indicate good stability of the analyzers in the face of an instrument shutdown.

6.1.5 Interferences

Table 6-8 lists the data obtained in the interference tests. Table 6-9 summarizes the sensitivity of the analyzers to interferant species, based on the data from Table 6-8. The results in Table 6-8 use the average of the zero readings before and after the interferant exposure to calculate the extent of the interference.

Table 6-9 indicates that there were no significant interference effects from CO, CO₂, NH₃, HCs, and SO₂, or from SO₂ in the presence of NO. The response to 393 ppm NO was only slightly decreased by the presence of 451 ppm SO₂ (i.e., readings were 0.7 to 2.9% lower than the 303 ppm NO provided). This degree of difference is within the $\pm 4\%$ accuracy specification of the Lancom Series II analyzers, and thus no significant effect of SO₂ is inferred.

Table 6-4. Response Time Data for Land Combustion LANCOM Series II Analyzers

Time (sec)	Unit A NO (ppm)	Unit A NO₂ (ppm)	Unit B NO (ppm)	Unit B NO₂ (ppm)
0	2	1	3	0
10	15	1	5	1
20	546	48	439	43
30	1284	184	1160	172
40	1383	262	1357	249
50	1398	303	1385	291
60	1400	317	1388	305
70	1402	325	1392	314
80	1403	329	1393	319
90	1404	332	1395	322
100	1405	334	1395	324
110	1405	335	1396	326
120	1406	337	1397	328
130	1406	338	1398	329
140	1406	339	1398	330
150		340		332
160		340		332
170		341		333
180		341		334
190		342		334
200		342		335
210		343		335
220		343		336
230		343		336
240		344		337
250		344		337
260		344		338
270		345		338
280		345		338
290		345		338
300		345		339

Table 6-5. Response Time Results for Land Combustion LANCOM Series II Analyzers

	Unit A		Unit B	
	NO	NO ₂	NO	NO ₂
Response Time (sec) ^a	35	77	39	90

^a The analyzer's responses were recorded at 10-second intervals; therefore the point in time when the 95 percent response was achieved was determined by interpolating between recorded times to the nearest second.

Table 6-6. Data from Interrupted Sampling Test with Land Combustion LANCOM Series II Analyzers

	Unit A NO	Unit A NO ₂	Unit B NO	Unit B NO ₂
Pre-Shutdown Date:	05/22/2000	Time:	17:17	
Pre-Shutdown Zero (ppm):	3	1	3	1
Pre-Shutdown Span (ppm):	2006	519	1955	514
Post-Shutdown Date:	05/23/2000	Time:	09:05	
Post-Shutdown Zero (ppm):	2	2	1	3
Post-Shutdown Span (ppm):	1940	520	1941	525

Table 6-7. Pre- to Post-Test Differences as a Result of Interruption of Operation of Land Combustion LANCOM Series II Analyzers

Pre-Shutdown—Post-Shutdown	Unit A		Unit B	
	NO	NO ₂	NO	NO ₂
Zero Difference (ppm)	1	-1	2	-2
Span Difference (ppm)	66	-1	14	-11

Table 6-8. Data from Interference Tests on Land Combustion LANCOM Series II Analyzers

Interferant Gas	Interferant, Conc. (ppm)	Response (ppm equivalent)			
		Unit A	Unit A NO ₂	Unit B NO	Unit B NO ₂
Zero		1	0	0	0
CO	496	1	0	0	0
Zero		0	0	0	0
CO ₂	5.03%	1	0	0	0
Zero		1	0	0	0
NH ₃	494	1	0	0	0
Zero		1	0	0	0
HCs	605	1	0	0	0
Zero		1	0	0	0
SO ₂	501	1	0	0	0
Zero		1	0	0	0
SO ₂ + NO	451 + 393	380	0	390	1

Table 6-9. Results of Interference Tests of Land Combustion LANCOM Series II Analyzers

Interferant	Unit A Response ppm (relative sensitivity, %)		Unit B Response ppm (relative sensitivity, %)	
	NO	NO ₂	NO	NO ₂
CO (496 ppm)	0.1%	0	0	0
CO ₂ (5.03%)	0	0	0	0
NH ₃ (494 ppm)	0	0	0	0
HCs (605 ppm)	0	0	0	0
SO ₂ (501 ppm)	0	0	0	0
SO ₂ (451 ppm) + NO (393 ppm)	-2.9%	0	-0.7%	0.2%

6.1.6 Pressure Sensitivity

Table 6-10 lists the data obtained in the pressure sensitivity test. Table 6-11 summarizes the findings from those data in terms of the ppm differences in zero and span readings at the different duct gas pressures and the ccm differences in analyzer flow rates at the different duct gas pressures.

Tables 6-10 and 6-11 show that only very small changes in LANCOM Series II zero and span readings resulted from the changes in duct pressure, for both NO and NO₂. Average zero readings changed by less than 1 ppm, and span readings changed by no more than 12 ppm for NO (0.9 % of the 1,400 ppm span level) and 6 ppm for NO₂ (1.7% of the 350 ppm span level). For both NO and NO₂, the span responses were slightly higher under both the reduced and increased pressure conditions, relative to those at atmospheric pressure. The changes observed do not indicate any statistically significant effect of pressure on zero or span readings.

Tables 6-10 and 6-11 also show only a small effect of pressure on the sample flow rates of the LANCOM Series II analyzers. The reduced pressure condition reduced the flow rates by about 3.5%, and the increased pressure condition increased the flow rates by about 2%, relative to the flows at ambient pressure.

6.1.7 Ambient Temperature

Table 6-12 lists the data obtained in the ambient temperature test with the Land Combustion LANCOM Series II analyzers. Table 6-13 summarizes the sensitivity of the analyzers to changes in ambient temperature. This table is based on the data shown in Table 6-12.

Tables 6-12 and 6-13 show that the temperature variations in this test had no significant effect on the NO₂ zero readings of either LANCOM Series II analyzer. However, a statistically significant but small temperature effect was indicated for the NO zero readings. This result is entirely due to the slightly elevated NO zero readings observed when the analyzers were placed in the heated chamber (Table 6-12).

Temperature did have a significant effect on the NO and NO₂ span responses of both LANCOM Series II analyzers. The effect was consistent for both NO and NO₂ with both LANCOM units, in that higher span responses occurred at higher temperatures, and lower responses at lower temperatures, relative to the responses at room temperature. The total difference in span readings between the cooled and heated environments was 7 to 10% of the 1,400 ppm NO span value, and about 4% of the 350 ppm NO₂ span value. Note that the vendor recommends calibrating at the same temperature at which measurements will be made, and re-zeroing in the event of a temperature change greater than 20°F.

Table 6-10. Data from Pressure Sensitivity Test for Land Combustion LANCOM Series II Analyzers

Pressure		Unit A NO	Unit A NO ₂	Unit B NO	Unit B NO ₂
Ambient	Flow rate (ccm)	1324	1324	1691	1691
	Zero (ppm)	1	0	0	0
	NO span (ppm)	1367	1	1397	1
	Zero (ppm)	2	0	2	0
	NO ₂ span (ppm)	1	349	1	355
	Zero (ppm)	2	1	1	1
+10 in. H ₂ O	Flow rate (ccm)	1358	1358	1723	1723
	Zero (ppm)	2	0	2	0
	NO span (ppm)	1374	1	1406	1
	Zero (ppm)	2	0	2	0
	NO ₂ span (ppm)	2	355	1	361
	Zero (ppm)	2	2	1	2
-10 in. H ₂ O	Flow rate (ccm)	1279	1279	1629	1629
	Zero (ppm)	2	0	1	0
	NO span (ppm)	1379	1	1406	1
	Zero (ppm)	3	0	2	0
	NO ₂ span (ppm)	2	354	1	361
	Zero (ppm)	2	1	1	2

Table 6-11. Pressure Sensitivity Results for Land Combustion LANCOM Series II Analyzers

		Unit A		Unit B	
		NO	NO ₂	NO	NO ₂
Zero	High–Ambient (ppm diff ^a)	0.334	0.334	0.667	0.334
	Low–Ambient (ppm diff)	0.667	0	0.333	0.334
	Significant Pressure Effect	N	N	N	N
Span	High–Ambient (ppm diff)	7	6	9	6
	Low–Ambient (ppm diff)	12	5	9	6
	Significant Pressure Effect	N	N	N	N
Flow Rate	High–Ambient (ccm diff ^a)	34		32	
	Low–Ambient (ccm diff)	-45		-62	

^a ppm or ccm difference between high/low and ambient pressures. The differences were calculated based on the average of the zero values.

Table 6-12. Data from Ambient Temperature Test of Land Combustion LANCOM Series II Analyzers

Condition	Unit A NO (ppm)	Unit A NO ₂ (ppm)	Unit B NO (ppm)	Unit B NO ₂ (ppm)
(Room Temp.)				
Temp. 25.56°C (78°F)				
Zero	0	0	0	0
NO span	1381	4	1422	6
Zero	1	1	1	1
NO ₂ span	0	355	1	360
(Heated)				
Temp. 39.44°C (103°F)				
Zero	5	0	2	0
NO span	1448	2	1494	2
Zero	9	0	5	0
NO ₂ span	13	363	9	367
(Cooled)				
Temp. 7.22°C (45°F)				
Zero	1	2	0	2
NO span	1351	5	1356	7
Zero	1	0	0	0
NO ₂ span	0	349	0	352
(Room Temp.)				
Temp. 22.78°C (73°F)				
Zero	0	0	0	0
NO span	1369	2	1388	2
Zero	3	0	1	0
NO ₂ span	4	356	0	361

6.1.8 Zero/Span Drift

Zero and span drift were evaluated from data taken at the start and end of the linearity and ambient temperature laboratory tests. Those data are shown in Table 6-14, and the drift values observed are shown as pre- minus post-test differences in ppm in Table 6-15.

Table 6-13. Ambient Temperature Effects on Land Combustion LANCOM Series II Analyzers

		Unit A		Unit B	
		NO	NO ₂	NO	NO ₂
Zero ^a	Heat–Room (ppm diff)	6	-0.25	3	-0.25
	Cool–Room (ppm diff)	0	0.75	-0.5	0.75
	Significant Temp Effect	Y	N	Y	N
Span ^a	Heat–Room (ppm diff)	73	7.5	89	6.5
	Cool–Room (ppm diff)	-24	-6.5	-49	-8.5
	Significant Temp. Effect	Y	Y	Y	Y

^a ppm difference between heated/cooled and room temperatures. The differences were calculated using the average of two recorded responses at room temperature (Table 6-12).

Table 6-14. Data from Linearity and Ambient Temperature Tests Used to Assess Zero and Span Drift of the Land Combustion LANCOM Series II Analyzers

Test		Unit A NO (ppm)	Unit A NO ₂ (ppm)	Unit B NO (ppm)	Unit B NO ₂ (ppm)
Linearity	Pre-Test Zero	2	0	3	0
	Pre-Test Span	1998	507	1978	496
	Post-Test Zero	3	2	4	1
	Post-Test Span	2020	512	1995	501
Ambient Temperature	Pre-Test Zero	0	1	0	1
	Pre-Test Span	1381	355	1422	360
	Post-Test Zero	0	0	0	0
	Post-Test Span	1369	356	1388	361

Table 6-15. Zero and Span Drift Results for the Land Combustion LANCOM Series II Analyzers

		Unit A		Unit B	
Pre- and Post-Differences		NO (ppm)	NO ₂ (ppm)	NO (ppm)	NO ₂ (ppm)
Linearity Test	Zero	-1	-2	-1	-1
	Span	-22	-5	-17	-5
Ambient Temperature Test	Zero	-1	0.5	0	0.5
	Span	12	-1	34	-1

Table 6-15 shows that zero drifts in these tests were 2 ppm or less for both NO and NO₂ on both LANCOM Series II analyzers. This result indicates minimal effect of exposure to the high NO and NO₂ levels in the linearity test. Span drift for NO₂ amounted to 5 ppm or less (about 1% of the 512 ppm span value). Span drift for NO amounted to 22 ppm or less in the linearity test (1.1% of the 2,000 ppm NO span value) and was 34 ppm or less in the ambient temperature test (2.4% of the 1,400 ppm NO span value).

6.2 Combustion Source Tests

6.2.1 Relative Accuracy

Tables 6-16a through d list the measured NO, NO₂, and NO_x data obtained in sampling the four combustion sources. Note that the LANCOM Series II analyzers measure NO and NO₂, and the indicated NO_x readings are the sum of those data. On the other hand, the reference analyzers measure NO and NO_x, with NO₂ determined by difference.

Table 6-17 displays the relative accuracy (in percent) for NO, NO₂, and NO_x of Units A and B for each of the four sources. Estimated standard errors are shown with the relative accuracy estimates. These standard error estimates were calculated under the assumption of zero true bias between the reference and test methods. If the bias is in fact non-zero, the standard errors underestimate the variability.

Table 6-17 shows that relative accuracy for NO_x ranged from 1.8 to 17.5% over both analyzers and all combustion sources. Relative accuracy for NO ranged from 1.2 to 21%, and the relative accuracy for NO₂ ranged from 4.2 to 26%. Relatively accuracy was generally better at higher concentrations. At NO and NO₂ levels of 6 ppm or less, the LANCOM Series II analyzers were accurate to within about their 1-ppm measurement resolution.

Table 6-16a. Data from Gas Rangetop in Verification Testing of Land Combustion LANCOM Series II Analyzers

	Land Combustion Analyzer Data						Reference Analyzer Data					
	Unit A			Unit B			Unit 100643			Unit 100647		
	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)
1	6	3	9	5	3	8	5.47	1.98	7.44	4.80	2.27	7.07
2	6	2	8	6	2	8	5.96	1.89	7.85	5.24	2.32	7.57
3	7	2	9	6	2	8	6.12	1.82	7.93	5.46	2.16	7.63
4	7	2	9	6	2	8	6.27	1.73	8.00	5.62	2.19	7.81
5	7	2	9	6	2	8	6.33	1.76	8.09	5.58	2.31	7.89
6	7	2	9	7	2	9	6.38	1.91	8.29	5.63	2.32	7.95
7	7	2	9	6	2	8	6.51	1.91	8.42	5.70	2.38	8.08
8	8	2	10	7	2	9	6.70	1.86	8.57	6.08	2.14	8.22
9	7	2	9	7	2	9	6.51	1.77	8.28	5.82	2.14	7.96

Table 6-16b. Data from Gas Water Heater in Verification Testing of Land Combustion LANCOM Series II Analyzers

	Land Combustion Analyzer Data						Reference Analyzer Data					
	Unit A			Unit B			Unit 100643			Unit 100647		
	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)
1	79	5	84	79	5	84	80.7	3.5	84.2	79.3	4.24	83.5
2	80	5	85	81	5	86	80.2	4.0	84.3	79.0	4.44	83.4
3	80	6	86	81	5	86	81.3	4.9	86.3	79.9	4.65	84.5
4	78	6	84	80	5	85	79.4	4.6	84.0	77.8	4.85	82.7
5	79	6	85	80	5	85	78.5	4.6	83.1	77.4	4.34	81.8
6	79	6	85	80	5	85	79.8	4.6	84.4	77.7	5.56	83.3
7	80	5	85	81	5	86	79.5	5.0	84.6	78.3	5.15	83.5
8	80	5	85	81	5	86	79.9	4.7	84.6	78.2	5.45	83.7
9	82	6	88	83	5	88	80.5	5.4	85.9	79.3	5.66	84.9

Table 6-16c. Data from Diesel Generator at High RPM in Verification Testing of Land Combustion LANCOM Series II Analyzers

	Land Combustion Analyzer Data					Reference Analyzer Data				
	Unit A					Unit B				
	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
1	165	73	238	171	72	243	165.2	75.7	240.9	163.8
2	155	69	224	161	68	229	157.4	70.2	227.7	156.1
3	157	69	226	164	68	232	156.5	66.9	223.4	156.1
4	155	68	223	163	68	231	156.5	69.1	225.6	156.1
5	158	68	226	166	67	233	160.3	66.9	227.3	159.0
6	156	70	226	164	69	233	159.4	70.2	229.6	159.0
7	158	65	223	166	65	231	159.4	66.9	226.3	159.0
8	160	66	226	169	66	235	157.4	65.8	223.3	157.0
9	157	66	223	164	65	229	156.5	63.6	220.1	155.1

Table 6-16d. Data from Diesel Generator at Idle in Verification Testing of Land Combustion LANCOM Series II Analyzers

	Land Combustion Analyzer Data					Reference Analyzer Data				
	Unit A					Unit B				
	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO (ppm)	NO _x (ppm)
1	219	100	319	226	100	326	219.6	109.7	329.4	217.7
2	215	101	316	220	100	320	215.7	108.6	324.4	214.8
3	208	100	308	213	100	313	211.9	109.7	321.6	210.0
4	215	101	316	222	100	322	217.7	107.5	325.2	216.8
5	207	103	310	218	101	319	210.9	109.7	320.6	210.0
6	206	104	310	212	102	314	208.0	108.6	316.6	208.1
7	199	102	301	204	100	304	204.1	107.5	311.6	204.2
8	196	101	297	200	100	300	200.2	108.6	308.8	200.4
9	193	101	294	201	100	301	202.1	106.4	308.6	202.3

Table 6-17. Relative Accuracy of Land Combustion LANCOM Series II Analyzers

Source	Unit A			Unit B		
	NO (%)	NO ₂ (%)	NO _x (%)	NO (%)	NO ₂ (%)	NO _x (%)
Gas Rangetop (6 ppm NO, 2 ppm NO ₂) ^c	21.021 ^a (1.524) ^b	14.747 (4.243)	17.496 (1.535)	10.863 (1.939)	14.747 (4.243)	8.802 (1.425)
Gas Water Heater (80 ppm NO, 5 ppm NO ₂)	1.473 (0.352)	26.019 (3.420)	2.181 (0.279)	2.890 (0.409)	13.103 (2.965)	2.712 (0.280)
Diesel Generator–High RPM (160 ppm NO, 70 ppm NO ₂)	1.160 (0.324)	4.156 (0.680)	1.844 (0.349)	5.492 (0.382)	5.052 (0.659)	3.224 (0.410)
Diesel Generator–Idle (210 ppm NO, 110 ppm NO ₂)	2.594 (0.377)	9.356 (0.430)	4.472 (0.231)	2.720 (0.434)	9.991 (0.295)	2.867 (0.252)

^a Relative accuracy, percent relative to mean of two reference analyzers.

^b Standard error of the relative accuracy value.

^c Approximate NO and NO₂ levels from each source are shown; see Tables 6-16a through d.

The unit-to-unit agreement of the LANCOM Series II analyzers in source combustion tests was also good. For example, the differences between the average NO_x values obtained by LANCOM Units A and B on the four combustion sources ranged from 0.5 to 7.7%, relative to the mean NO_x values; the corresponding agreement of the two reference analyzers ranged from 1.0 to 3.8%. These results indicate a high degree of consistency in the performance of the LANCOM analyzers on combustion sources.

6.2.2 Zero/Span Drift

Table 6-18 shows the data used to evaluate zero and span drift of the LANCOM Series II analyzers from the combustion source tests.

Table 6-19 summarizes the zero and span drift results, showing that zero and span drift was rarely more than a few ppm in any of the combustion source tests, for either NO or NO₂, with either analyzer. The zero drift values exceeded ± 1 ppm only for NO readings of the LANCOM Series II analyzers with the diesel generator. Those NO zero drift values with the diesel source are about 1% of the 200 ppm and 400 ppm NO span values used with that source.

The span drift values in Table 6-19 are similarly small. Relative to the respective span values, the NO span drift was at most 5% of span (relative to the 20 ppm span value used with the gas rangetop), and the NO₂ span drift was, at most, 10% (relative to the 10 ppm span value used with the rangetop). These zero and span drift results reflect the ± 1 ppm resolution of the analyzers and are consistent with those obtained in the laboratory testing (Section 6.1.8).

Table 6-18. Data Used to Assess Zero and Span Drift for Land Combustion LANCOM Series II Analyzers on Combustion Sources

Source		Unit A NO (ppm)	Unit A NO ₂ (ppm)	Unit B NO (ppm)	Unit B NO ₂ (ppm)
Gas Rangetop	Pre-Test Zero	1	0	1	0
	Pre-Test Span	19	10	19	10
	Post-Test Zero	2	0	1	0
	Post-Test Span	20	10	19	9
Gas Water Heater	Pre-Test Zero	3	0	1	0
	Pre-Test Span	100	14	100	14
	Post-Test Zero	3	0	2	0
	Post-Test Span	100	14	100	13
Diesel–High RPM	Pre-Test Zero	3	0	3	0
	Pre-Test Span	202	46	202	46
	Post-Test Zero	0	1	0	1
	Post-Test Span	199	47	203	46
Diesel–Idle	Pre-Test Zero	0	0	0	0
	Pre-Test Span	391	100	395	98
	Post-Test Zero	3	0	1	0
	Post-Test Span	386	101	386	98

Table 6-19. Results of Zero and Span Drift Evaluation for Land Combustion LANCOM Series II Analyzers

		Unit A		Unit B	
	Pre-Test— Post-Test	NO (ppm)	NO ₂ (ppm)	NO (ppm)	NO ₂ (ppm)
Gas Rangetop	Zero	-1	0	0	0
	Span	-1	0	0	1
Gas Water Heater	Zero	0	0	-1	0
	Span	0	0	0	1
Diesel Generator—High RPM	Zero	3	-1	3	-1
	Span	3	-1	-1	0
Diesel Generator—Idle	Zero	-3	0	-1	0
	Span	5	-1	9	0

6.2.3 Measurement Stability

Table 6-20 shows the data obtained in the extended sampling test, in which the LANCOM Series II and reference analyzers sampled diesel emissions for a full hour without interruption or sampling of ambient air. Table 6-21 shows the results of this evaluation in terms of the slopes and standard errors of the NO, NO₂, and NO_x data with time. Also shown in Table 6-21 is an indication of whether the slopes observed by the LANCOM Series II analyzers differed from those observed by the reference analyzers.

Table 6-21 shows that both the LANCOM Series II analyzers and the reference analyzers indicated increasing trends in NO and NO_x, and a decreasing trend in NO₂, during the extended sampling of the diesel source. The slopes of the trends determined by the LANCOM Series II analyzers were very close to the slopes determined by the reference analyzers. As a result, there was no statistically significant difference between the trends determined by the LANCOM Series II and the reference analyzers.

6.2.4 Inter-Unit Repeatability

The repeatability of test results between the two LANCOM Series II analyzers was assessed in those cases where the data lent themselves to application of a t-test. The resulting t-statistics and associated p-values are listed in Table 6-22. Highlighted in bold are those p-values less than 0.05, which indicate a statistically significant difference between the two LANCOM Series II units at the 95% confidence level. Significant unit-to-unit differences were found primarily in the area of relative accuracy.

Table 6-20. Data from Extended Sampling Test with Diesel Generator at Idle, Using Land and Combustion LANCOM Series II Analyzers

	Land Combustion Analyzer Data						Reference Analyzer Data					
	Unit A			Unit B			Unit 100643			Unit 100647		
	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)
1	178	103	281	182	100	282	185.6	106.4	292.1	185.0	109.5	294.4
2	176	102	278	179	101	280	183.7	108.6	292.3	183.0	112.4	295.5
3	174	103	277	177	100	277	182.7	105.3	288.0	181.1	109.5	290.6
4	171	102	273	175	100	275	182.7	107.5	290.2	180.2	112.4	292.6
5	169	104	273	175	101	276	178.8	106.4	285.3	178.2	110.5	288.7
6	168	102	270	172	100	272	177.8	105.3	283.2	177.3	108.5	285.7
7	165	103	268	170	102	272	177.8	105.3	283.2	177.3	110.5	287.7
8	166	102	268	169	100	269	175.9	104.2	280.1	174.4	108.5	282.9
9	166	103	269	176	102	278	178.8	105.3	284.2	180.2	110.5	290.6
10	161	104	265	165	102	267	172.0	106.4	278.4	171.5	111.4	282.9
11	162	102	264	165	101	266	171.0	107.5	278.6	170.5	111.4	282.0
12	163	105	268	167	102	269	171.0	106.4	277.5	170.5	111.4	282.0
13	162	102	264	165	100	265	171.0	105.3	276.4	170.5	109.5	280.0
14	172	104	276	172	102	274	171.0	104.2	275.3	170.5	110.5	281.0
15	162	104	266	165	101	266	174.0	104.2	278.2	174.4	107.5	281.9
16	158	105	263	159	103	262	169.1	105.3	274.4	169.6	110.5	280.0
17	169	99	268	172	97	269	177.8	103.1	281.0	177.3	107.5	284.8
18	170	101	271	170	98	268	175.9	101.0	276.8	175.3	104.5	279.9
19	167	99	266	170	97	267	180.8	104.2	285.0	177.3	109.5	286.7
20	167	102	269	168	99	267	176.9	102.0	278.9	176.3	106.5	282.8
21	163	99	262	166	97	263	175.9	105.3	281.2	174.4	107.5	281.9
22	162	100	262	167	98	265	175.9	101.0	276.8	176.3	105.5	281.8
23	163	97	260	166	95	261	173.0	99.9	272.8	172.4	104.5	277.0
24	164	98	262	172	97	269	176.9	99.9	276.7	179.2	104.5	283.7
25	160	100	260	164	97	261	172.0	101.0	273.0	171.5	105.5	277.0
26	160	98	258	162	97	259	169.1	104.2	273.3	168.6	108.5	277.1
27	164	99	263	163	97	260	171.0	99.9	270.9	169.6	105.5	275.1
28	159	97	256	162	95	257	170.1	102.0	272.1	169.6	104.5	274.1
29	161	99	260	163	96	259	169.1	101.0	270.0	167.6	104.5	272.2
30	160	97	257	164	95	259	176.9	101.0	277.8	175.3	107.5	282.8

Table 6-20. Data from Extended Sampling Test with Diesel Generator at Idle, Using Land and Combustion LANCOM Series II Analyzers (continued)

	Land Combustion Analyzer Data						Reference Analyzer Data					
	Unit A			Unit B			Unit 100643			Unit 100647		
	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)	NO (ppm)	NO ₂ (ppm)	NO _x (ppm)
31	159	98	257	162	96	258	172.0	98.8	270.8	171.5	102.6	274.0
32	163	95	258	168	93	261	174.0	98.8	272.7	174.4	102.6	276.9
33	157	98	255	164	96	260	173.0	98.8	271.7	173.4	102.6	276.0
34	161	95	256	164	93	257	172.0	98.8	270.8	171.5	104.5	276.0
35	172	96	268	178	95	273	174.9	98.8	273.7	175.3	103.6	278.9
36	161	94	255	165	92	257	175.9	95.5	271.4	175.3	99.6	274.9
37	177	97	274	180	94	274	186.6	92.2	278.8	186.9	97.6	284.5
38	177	96	273	181	93	274	189.5	95.5	285.0	190.8	98.6	289.4
39	177	96	273	180	94	274	186.6	102.0	288.6	186.9	105.5	292.4
40	177	97	274	180	95	275	186.6	96.6	283.2	186.9	101.6	288.5
41	180	95	275	183	93	276	192.4	98.8	291.2	192.7	101.6	294.3
42	181	99	280	183	95	278	190.5	98.8	289.2	190.8	102.6	293.3
43	182	96	278	185	93	278	192.4	98.8	291.2	192.7	103.6	296.2
44	182	97	279	183	95	278	193.4	98.8	292.1	193.6	102.6	296.2
45	185	98	283	188	92	280	195.3	96.6	291.9	194.6	100.6	295.2
46	183	95	278	187	93	280	199.2	98.8	298.0	199.4	102.6	302.0
47	180	98	278	183	93	276	194.4	96.6	290.9	193.6	100.6	294.2
48	182	93	275	185	91	276	194.4	95.5	289.8	194.6	99.6	294.2
49	204	95	299	206	94	300	194.4	101.0	295.3	195.6	106.5	302.1
50	206	94	300	210	92	302	216.7	96.6	313.3	216.8	100.6	317.4
51	210	96	306	213	94	307	219.6	96.6	316.2	219.7	102.6	322.2
52	205	97	302	208	95	303	218.7	97.7	316.3	219.7	101.6	321.2
53	206	97	303	209	95	304	214.8	99.9	314.6	214.8	104.5	319.4
54	204	100	304	207	97	304	210.9	103.1	314.0	211.0	106.5	317.5
55	207	98	305	210	95	305	215.7	99.9	315.6	216.8	103.6	320.3
56	206	99	305	209	97	306	215.7	101.0	316.7	215.8	106.5	322.3
57	207	100	307	209	97	306	215.7	101.0	316.7	215.8	105.5	321.3
58	207	99	306	209	97	306	215.7	103.1	318.9	215.8	107.5	323.3
59	207	100	307	211	98	309	218.7	101.0	319.6	218.7	105.5	324.2
60	205	99	304	205	95	300	217.7	99.9	317.5	218.7	103.6	322.2

Table 6-21. Results of Evaluation of Measurement Stability for Land Combustion LANCOS Series II Analyzer

	Unit A			Unit B			Reference Units		
	NO	NO ₂	NO _x	NO	NO ₂	NO _x	NO	NO ₂	NO _x
Slope (Std Err)	0.724 (0.083)	-0.120 (0.017)	0.604 (0.092)	0.703 (0.083)	-0.133 (0.016)	0.570 (0.092)	0.740 (0.077)	-0.149 (0.020)	0.592 (0.087)
Difference in Slopes ^a (ppm/min) (Std Err)	-0.016 (0.029)	0.028 (0.016)	0.012 (0.030)	-0.037 (0.027)	0.016 (0.013)	-0.022 (0.028)	---	---	---

^a There was no statistically significant difference in slope between the test units and the average of the reference units at the 5% significance level.

Table 6-22. Summary of Repeatability

Unit A vs. Unit B			NO	NO ₂	NO _x
Linear Regression	Intercept	t-statistic	-1.572	1.952	---
		p-value ^a	0.147	0.080	---
	Slope	t-statistic	0.249	5.965	---
		p-value	0.808	<0.001	---
Detection Limit		t-statistic	-0.002	0.786	---
		p-value	0.998	0.438 _b	---
Relative Accuracy	Gas Rangetop	t-statistic	4.000		4.000
		p-value	0.004	-	0.004
	Gas Water Heater	t-statistic	6.000	3.162	2.530
		p-value	<0.001	0.013	0.035
	Generator-High RPM	t-statistic	22.030	4.000	14.582
		p-value	<0.001	0.004	<0.001
	Generator-Idle	t-statistic	9.086	4.264	7.761
		p-value	<0.001	0.003	<0.001
Measurement Stability	Slope	t-statistic	1.640	1.850	2.100
		p-value	0.106	0.070	0.040

^a p-value <0.05 indicates that two test units are statistically different at the 5% significance level (in bold text).

^b Unit A and Unit B indicated exactly the same NO₂ readings on the gas burner emission. No matched-pairs t-statistic was calculated.

The differences shown in Table 6-22 indicate the variability that may be expected from one analyzer to the next. Although some statistically significant differences were found, nevertheless the practical importance of these differences is often small. Considering the relative accuracy results, for example (Table 6-17), it is apparent that statistically significant differences may exist even when the two analyzers are equally applicable to the measurement at hand. For example, the relative accuracy result for NO_x for Unit A on the water heater is 2.2%, whereas that for Unit B is 2.7%. These results may differ significantly in the statistical sense, but both units provided excellent accuracy in that portion of the test, and either unit would be more than adequate for determining the NO_x emissions from that source. The fine degree of discrimination provided by the statistical tests should not obscure the fact that the two LANCOM Series II analyzers worked about equally well throughout the verification tests.

6.3 Other Factors

In addition to the performance characteristics evaluated in the laboratory and combustion source tests, three additional factors were recorded: analyzer cost, data completeness, and maintenance/operational factors.

6.3.1 Cost

The cost of each analyzer as tested in this verification test was about \$12,500.

6.3.2 Data Completeness

The data completeness in the verification tests was 100% for both units of the LANCOM Series II analyzer.

6.3.3 Maintenance/Operational Factors

The short duration of the verification test prevented assessment of long-term maintenance costs, durability, etc. but no maintenance was needed and no problems occurred with the LANCOM Series II analyzers during this test.

Chapter 7

Performance Summary

The Land Combustion LANCOM Series II analyzers provided linear response for NO and NO₂ over the tested ranges of 0 to 2,000 ppm and 0 to 512 ppm, respectively. One of the LANCOM units did exhibit slightly low response to NO₂ above about 250 ppm, perhaps as a result of an older sensor used in that unit. Detection limits estimated from these wide-range linearity tests were about 2.5 ppm for NO and 1.5 to 2.3 ppm for NO₂. These results may have been affected by exposure to high NO and NO₂ levels in the linearity tests. Performance at low levels in combustion source tests indicated detection capabilities comparable to the 1-ppm resolution of the analyzers. Response times were 35 and 39 seconds for NO and 77 and 90 seconds for NO₂.

Drift in LANCOM Series II NO and NO₂ zero readings before and after source combustion and laboratory tests was within ± 2 ppm in nearly all circumstances. In laboratory tests, span drift for NO was within about 2%, using 1,400 to 2,000 ppm NO span levels. For NO₂, span drift was within 1%, using 350 to 512 ppm NO₂ span levels. In sampling gas combustion and diesel sources, absolute NO and NO₂ span drift was usually within 1 ppm, and span drift exceeded 2% of the span gas value only at span gas values of 10 to 20 ppm. No interference was found from any of the following: 496 ppm CO; 5.03% CO₂; 494 ppm NH₃; 605 ppm of total hydrocarbons; 501 ppm of SO₂; or 451 ppm SO₂ in the presence of 393 ppm NO.

Over the tested range of + 10 to - 10 in. H₂O, sample gas pressure had no significant effect on LANCOM Series II zero or span readings. Reduced pressure lowered the analyzers' sample flow rates by about 3.5%, and positive pressure increased the flow rates by about 2%. Variations in ambient temperature over the range of 7 to 39°C (45 to 103°F) had no effect on the LANCOM Series II zero readings for NO₂, but a small effect was seen for NO, with higher temperature increasing zero readings by a few ppm. Over that entire temperature range, span response increased with increasing temperature by 7 to 10% for NO, and by about 4% for NO₂.

The relative accuracy of the LANCOM Series II analyzers for NO_x ranged from 1.8 to 17.5% over both analyzers and all combustion sources. Relative accuracy for NO ranged from 1.2 to 21%, and the relative accuracy for NO₂ ranged from 4.2 to 26%. Relative accuracy was generally better at higher concentrations. At NO and NO₂ levels of 6 ppm or less, the LANCOM Series II analyzers were accurate to within about their 1-ppm measurement resolution. Unit-to-unit agreement for NO_x in source testing ranged from 0.5 to 7.7% and was comparable to that of the reference analyzers. Comparison of verification results from the two LANCOM Series II analyzers showed some unit-to-unit differences, primarily in relative accuracy; but overall the performance of the two analyzers was essentially the same.

Chapter 8

References

1. *Test/QA Plan for Verification of Portable NO/NO₂ Emission Analyzers*, Version 2.0, Battelle, Columbus, Ohio, August 1999.
2. *U.S. EPA Method 7E Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)* Code of Federal Regulations, 40 CFR, Ch 1, Part 60, Appendix A (1991).
3. *Traceability Protocol for Establishing True Concentrations of Gases Used for Calibrations and Audits of Continuous Source Emission Monitors: Protocol Number 1*, Research Triangle Park, NC: U.S. Environmental Protection Agency, Quality Assurance Division, June 1978.
4. *Interlaboratory Program to Validate a Protocol for the Measurement of NO₂ Emissions from Rangetop Burners*, GRI-94/0458, Gas Research Institute, Chicago, Illinois, December 1994.
5. *Interlaboratory Study to Determine the Precision of an Emission Measurement Protocol for Residential Gas Water Heaters*, GRI-96-0021, Gas Research Institute, Chicago, Illinois, March 1996.
6. American National Standards (ANSI Z21.1) "Household Cooking Gas Appliances," American National Standards Institute, 24th Edition, American Gas Association, 1990.
7. *Quality Management Plan (QMP) for the ETV Advanced Monitoring Systems Pilot*, U.S. EPA Environmental Technology Verification Program, Battelle, Columbus, Ohio, September 1998.
8. *Portable NO_x Analyzer Evaluation for Alternative Nitrogen Oxide Emission Rate Determination at Process Units*, Source Testing and Engineering Branch, South Coast Air Quality Management District, Los Angeles, CA, September 21, 1994.
9. *U.S. EPA Method 5, Determination of Particulate Emissions from Stationary Sources*, Code of Federal Regulations, 40 CFR, Ch. 1, Part 60, Appendix A (1991).
10. *Determination of Nitrogen Oxides, Carbon Monoxide, and Oxygen Emissions from Natural*

Gas-Fired Engines, Boilers, and Process Heaters Using Portable Analyzers, Conditional Test Method (CTM)-030, U.S. EPA, Office of Air Quality Planning and Standards, Emission Measurement Center, October 13, 1997.